AD-A049 379 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 9/2
COMPUTER AIDED DESIGN, POSSIBILITIES, NECESSITIES AND APPLICATI--ETC(U)
DEC 77

UNCLASSIFIED AGARD-R-662 NL

1 OF 1
AD A049379

END
DATE
FILMED
2-78
DDC

AGARD-R-662

# AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

**AGARD REPORT No. 662**

# Computer Aided Design

## Possibilities, Necessities and Applications in the Design Process



NORTH ATLANTIC TREATY ORGANIZATION

**DISTRIBUTION AND AVAILABILITY ON BACK COVER**

(1)

(14) AGARD-R-662

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

(11) Dec 77

AGARD Report No.662

(6) COMPUTER AIDED DESIGN,

Possibilities, Necessities and Applications

in the Design Process.

(12) 35p.





Two papers presented at the 45th Structures and Materials Panel Meeting,
Voss, Norway, September 1977.

400 043

mt

## THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Program and the Aerospace Applications Studies Program. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced
directly from material supplied by AGARD or the authors.

Published December 1977



ISBN 92-835-1267-7

*Printed by Technical Editing and Reproduction Ltd*
*Harford House, 7–9 Charlotte St, London, W1P 1HD*

# PREFACE

While some of the largest aerospace companies within the NATO community have already installed very complex, but nevertheless modulized software and hardware configurations for computer-aiding the design process in its different fields, other companies apply only specialized and/or isolated modules of software and hardware configurations.

This situation is caused not only by the engineering capacity and amount of money involved, but stems also from the lack of criteria by which the benefits of money invested may be estimated. The latter holds true especially because design directly causes only a small proportion of costs, whereas up to 80 percent of total product costs may be influenced by the design process. Thus much of the benefit of introducing more effective means and methods into the design process have to come downstream from material supply and manufacturing of a product.

From this it follows that each isolated module of software and hardware must not only fit into a general concept for the design process of one company, but must have a well defined interface with manufacturing facilities of the same company. This point becomes its special feature if cooperative programs between two or more aircraft companies in different countries are concerned.

The pilot papers contained in this publication will help to define the present possibilities, needs and applications of CAD in the design process, bearing in mind that design is not an aim in itself, but only one step towards manufacturing and selling a product.

R.J. MEYER-JENS
Chairman, Sub-Committee on
Computer Aided Design

## CONTENTS

# "COMPUTER AIDED STRUCTURAL DESIGN APPLIED TO PRODUCTION AIRCRAFT"

W. A. NORMAN
Senior Technical Specialist
McDonnell Aircraft Company
McDonnell Douglas Corporation
St. Louis, Mo. 63166

## ABSTRACT

McDonnell Aircraft Company (MCAIR), a division of McDonnell Douglas Corporation, has pioneered the development and application of computer aided design (CAD) to the point where all present projects utilize this technology to the maximum practical extent. The computer is used to aid the engineer in designing efficient structure and in preparing final drawings and releasing them to manufacturing. Engineering activities such as design drafting, lofting, and structural analysis utilize IBM 2250 interactive graphics terminals driven by the IBM 370 computer. This system accomplishes tasks previously done by hand or with batch computer procedures. For example, the design drafting capability allows the designer to establish the geometry of components, such as landing gears, in a fraction of the time required at the drawing board. Similarly, in determining internal loads and deflections, the computer graphics system relieves the structural engineer of many mundane tasks encountered in preparing computer input and reviewing computer output from analysis programs. This paper describes the engineering tasks accomplished with CAD and the computer hardware utilized.

## MCAIR COMPUTER AIDED STRUCTURAL DESIGN

Figure 1 depicts the five software modules used for the computer aided design (CAD) work performed by MCAIR engineering on aircraft design projects.

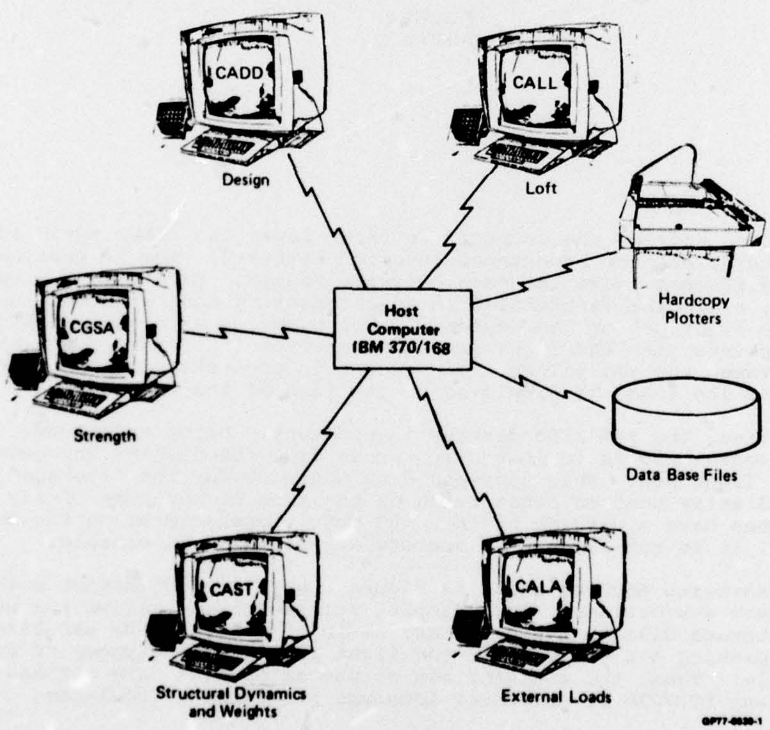



**FIGURE 1**
**MCAIR COMPUTER AIDED STRUCTURAL DESIGN**

- o CADD - Computer Aided Design Drafting (Design)
- o CALL - Computer Aided Loft Lines (Loft)
- o CGSA - Computer Graphics Structural Analysis (Strength)
- o CAST - Computer Aided Structural Technology (Structural Dynamics and Weights)
- o CALA - Computer Aided Loads Analysis (Loads)

These software modules are utilized via the IBM 2250 display unit model 3 device (Figure 2), driven by an IBM 370/168 host computer. The software packages were prepared by highly skilled computer programmers, but most console operators are engineers, with no computer programming knowledge. MCAIR has trained several hundred engineers to operate the "tube".

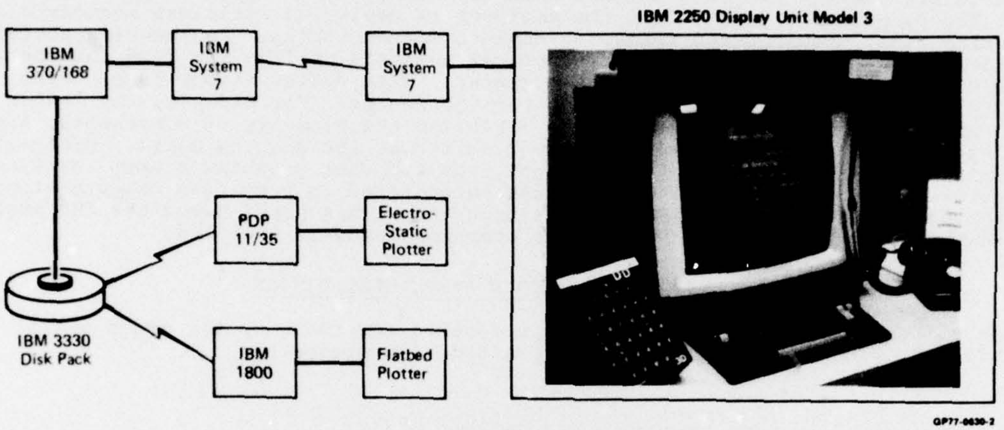



**FIGURE 2**
**HARDWARE**

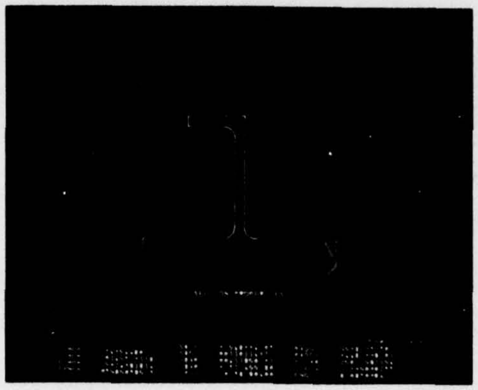
The operator can address the computer in three ways: the fiber optic light pen, the alphanumeric keyboard, and the programmed function keyboard. The 32 keys on the function keyboard perform different tasks for each software module. Each time the operator presses a function key, a program is executed in an interactive mode with the input coming primarily from the light pen or the keyboard. For example, when the operator of the CADD module picks two points with the light pen and depresses the "line" function key, he creates a line between the two points. The geometric properties of the line are stored in the computer and its image is displayed on the face of the tube.

During operation, the IBM 2250 display is constantly being refreshed. Thus, the typical mode of programming is to instantly remove from the display any geometric entity detected with the light pen. This approach does not work for the "storage" type CRT in which the entire display must be regenerated on the face of the tube if any entity is removed. MCAIR does have a version of the CADD module operational on the Tektronix storage tube; however, it is not as easy to operate as the IBM 2250 console.

Many of the software modules shown in Figure 1 work in conjunction with each other and have some common subroutines. For example, file/retrieval allows the user to file his data on the storage disk by typing in any title he chooses. He can later retrieve his "drawing" by picking his title, with the light pen, from the pages of such titles in his project file. Thus, the engineer can create an on-line data set and access that data set without any FORTRAN or Assembler Language programming knowledge.

One interesting feature involves a procedure called recoup. As the engineer developes his data, the program periodically stores a copy so if a computer failure occurs, the operator can recover his data except for the last few operations prior to failure. The entire file/retrieval capability in the computer graphics system represents a valuable and powerful file management technique.

Another general capability is the generation of hardcopies. Flatbed plotters provide ink on mylar engineering drawings accurate to .003 inch. Electrostatic plotters produce quick hardcopies when less accuracy is required. Unlike some hardcopy devices in which only the tube display is plotted, the engineer can plot all or any part of his data at any scale independent of the scale he sees displayed on the CRT. Each IBM 2250 is also equipped with a polaroid camera for quick photographs of the CRT. Figure 3 is a typical polaroid shot showing section properties.



GP77-0830-3

**FIGURE 3**
**POLAROID PHOTO**

## DESIGN DRAFTING

As far as the structures, or design engineer is concerned, the computer graphics system is centered on the Computer Aided Design Drafting (CADD) software module. Types of project work accomplished with this system are:

- o Geometric Studies
- o Sheet Metal Flat Patterns
- o Composite Materials Design
- o Fluid and Power Systems Design
- o Design of Machined Parts
- o Design Data Sheets
- o Assembly and Installation Drawings
- o Geometry Development for Math Models
- o Release of Design Drawings to Manufacturing

The CADD operator has the power to create and manipulate points, lines, circles, arcs, curves, and surfaces, as well as text. These entities have precise mathematical definitions and are located in X, Y, Z coordinate space. Some of the functions available include variable viewing direction and scale, translation, rotation, mirror image, ratio, scissoring, section cuts, section properties, intersect, geometric properties, flat pattern, kinematics, and erase/redisplay, as well as hardcopy and file/retrieval. The construction of the entities is independent of the viewing direction. The functions are very versatile thus allowing the engineer to be creative while solving his problems quickly and accurately.

Geometric Studies - A classic example of complicated three dimensional geometry is an aircraft landing gear design. Using CADD, designers can accomplish tasks involving rotation and translation in a fraction of the time required at the drawing board. Any type of descriptive geometry problem can be solved on the tube.

The design of control systems is aided by CADD with automated kinematics routines in three dimensional geometry. Figure 4 shows a computer-drawn hardcopy of geometric positions as an entire system of links and bell cranks moves through its path of travel.

Sheet Metal Flat Patterns - CADD is used to create flat pattern data for rubber-formed sheet metal parts. Figure 5 shows a typical flat pattern in a trimetric view. The input required includes light pen detection of mold lines and tutorial prompting to define flange width, bend radius, metal thickness, rivet spacing and edge distance. The bend angles, joggle lengths, flanges, form block lines, bend tangent lines and form block surfaces are generated automatically.
The mathematical definition is filed and released to manufacturing. The data is used to program numerically controlled milling machines which fabricate parts, forming dies and assembly fixtures.

Composite Materials Design - Laminated composite material presents new problems for the structural detailer. A design may have many plies of very thin orthotropic lamina (perhaps .0052 inch) and the designer must provide a flat pattern definition of each ply as well as a stacking sequence. The CADD operator has external loft lines available at the graphics console, and with skin thickness and taper rates from the structures group, is able to define the inner mold line of the composite skin. Figure 6 shows how the ply edge of part definitions are presented for release to the loft group for development of flat patterns for manufacturing.

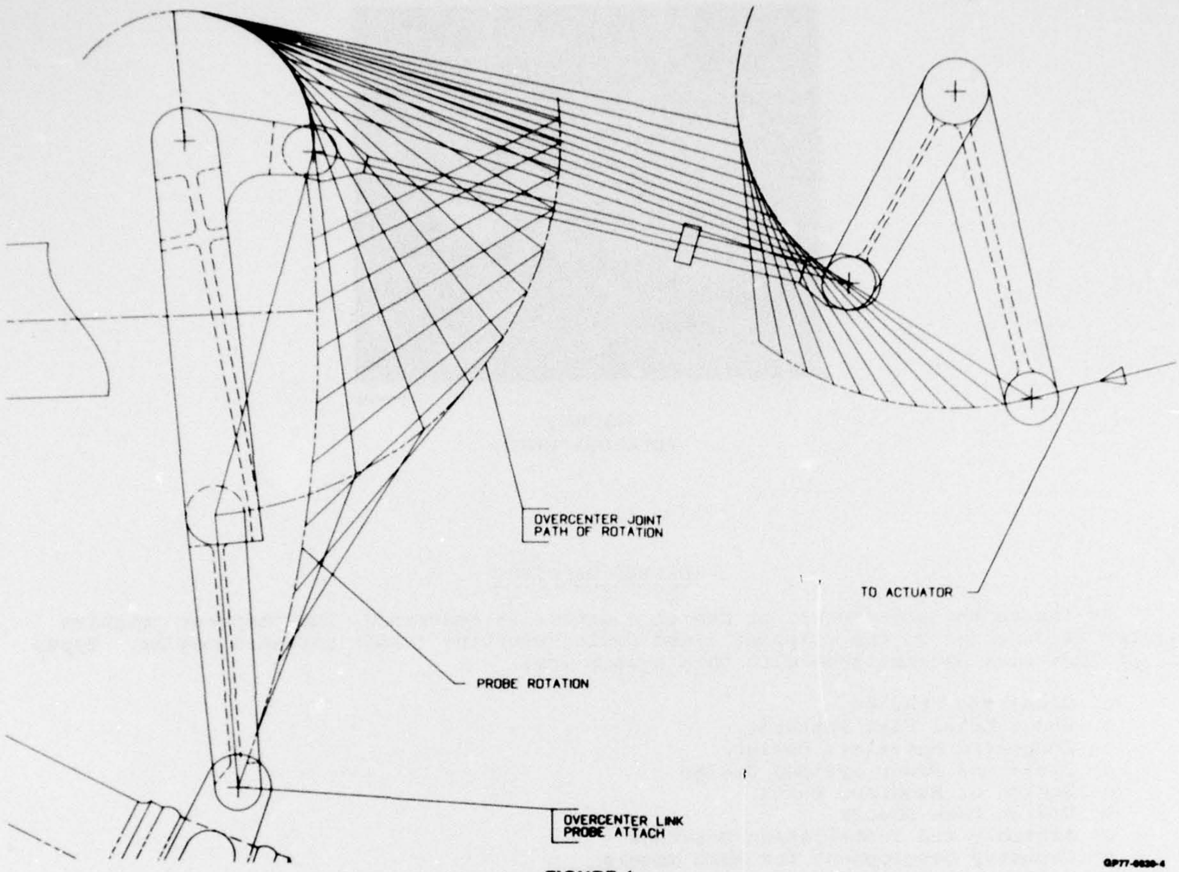



**FIGURE 4**
**LINKAGE**

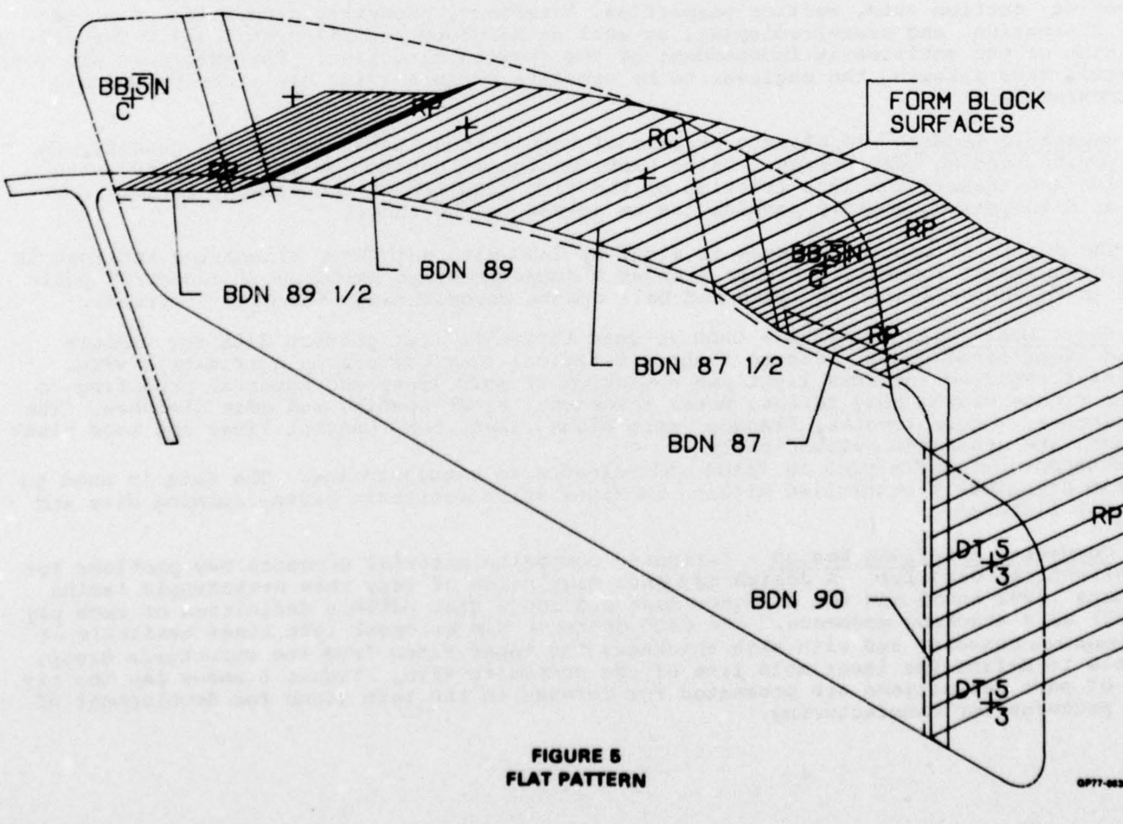



**FIGURE 5**
**FLAT PATTERN**

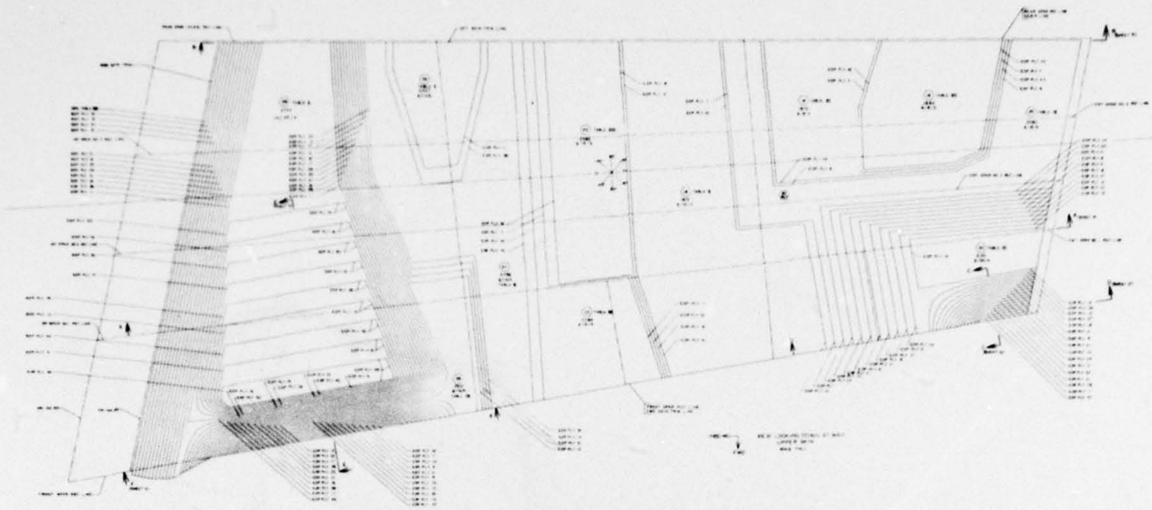



**FIGURE 6**
**COMPOSITES DRAWING**

CADD is also useful in developing cross-sectional through-the-ply definitions of how the plies are stacked. Figure 7 presents a typical cross-section in which CADD has been used to automatically exaggerate the vertical scale by a factor of 10.

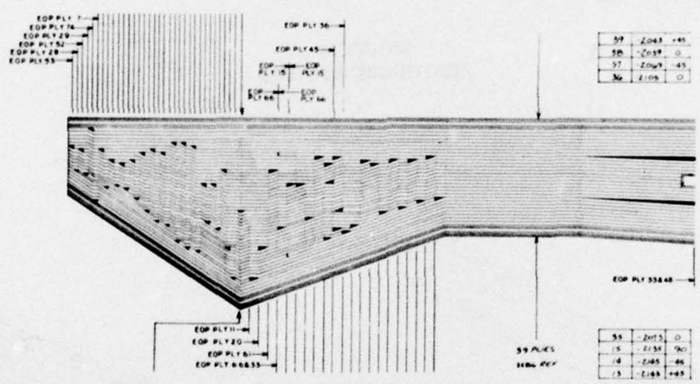
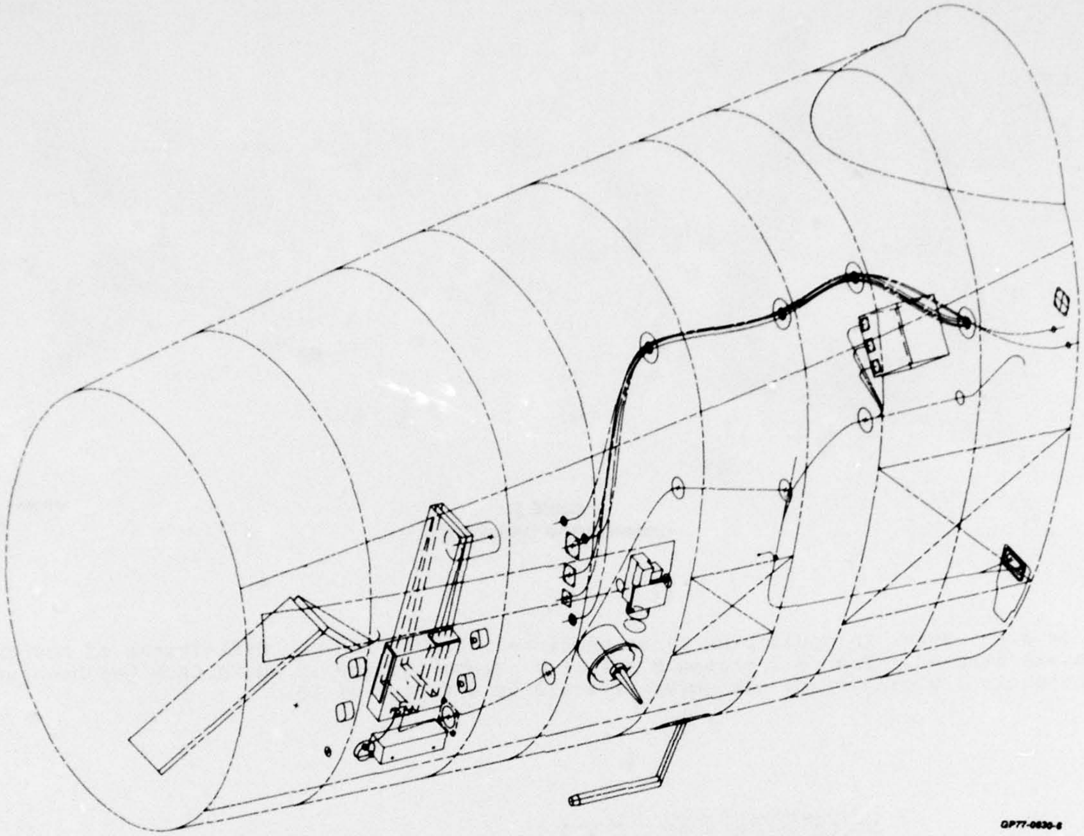



**FIGURE 7**
**COMPOSITES CROSS-SECTION**
Vertical Scale Exaggerated

The individual ply definitions are released to manufacturing within the computer, which facilitates the use of automated laser cutters and other computer aided manufacturing techniques.

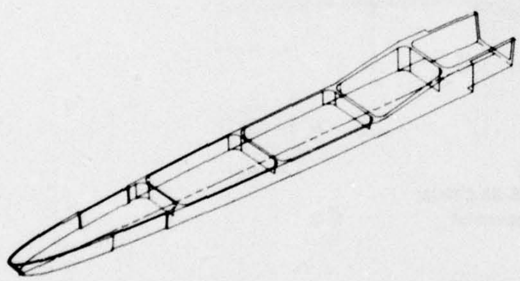
<u>Fluid and Power Systems Design</u> - CADD is used to define electrical, hydraulic, pneumatic, fuel system, and environmental control system centerlines. Figure 8 is a hard-copy of a trimetric view of selected forward fuselage electrical routing definitions. This type of data from the different disciplines can be merged together to check potential interferences. Manufacturing utilizes the computer stored data for mock-up construction and numerically controlled tube bending machines.

<u>Design of Machined Parts</u> - CADD is utilized in several different ways to produce definitions of machined parts, depending on the size of the part, the schedule, and manufacturing requests. Figure 9 shows a trimetric view of a "wire-frame" definition in which the intersections of the primary surfaces have been defined with lines and curves.



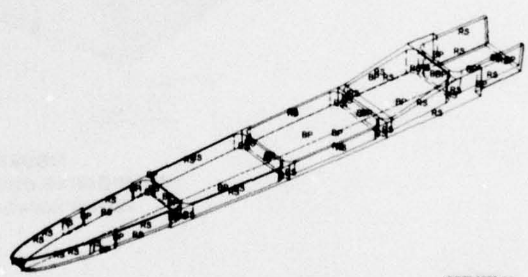
GP77-0630-6

FIGURE 8
ELECTRICAL ROUTING



GP77-0630-9

FIGURE 9
WIRE FRAME DEFINITION

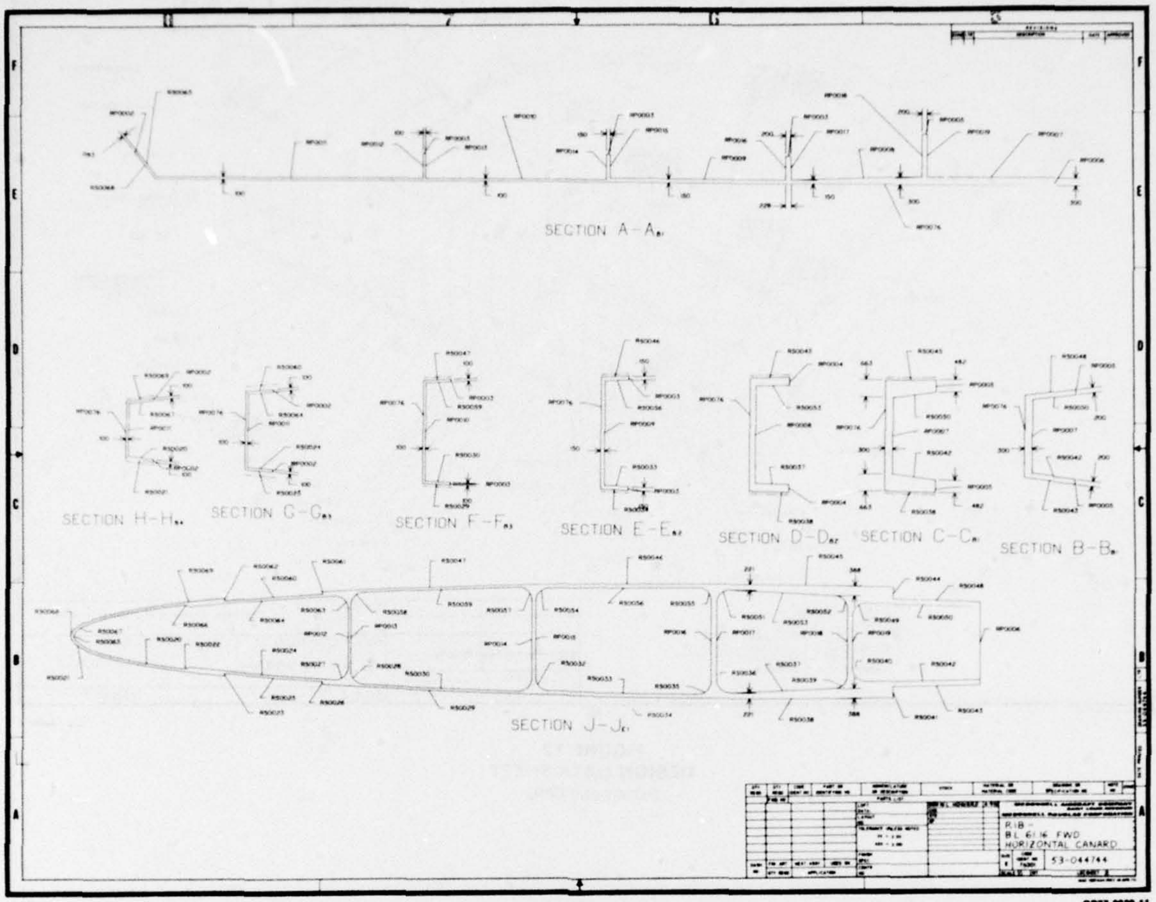


GP77-0630-10

FIGURE 10
SURFACE DEFINITION

Figure 10 is a hardcopy of a trimetric view of the same fitting with each surface mathematically defined in terms of surfaces. With the part completely surfaced, manufacturing can more readily analyze the surface geometry and generate the path of travel for a five-axis, direct numerically controlled milling machine.

Figure 11 is a conventional engineering drawing prepared at the graphics terminal using CADD. This particular two-dimensional drawing was developed from a complete surfaced definition, using automated section cut and dimensioning routines which also locate the sections on the page. The labels of the surfaces being intersected are referenced on the drawing. Normal engineering drawings of parts not surfaced can be "drawn" at the graphics terminal as well.




GP77-0830-11

**FIGURE 11**
**CADD DRAWING**

The use of CADD for defining machines parts with mathematical surfaces is not being exercised as frequently as other applications. The definition of very large machinings produces massive amounts of computer stored data. Development work by engineering and manufacturing to manage this data is continuing. However, it has been used very effectively for small parts and also for applications in which both the "tube" and drawing board are utilized to produce the engineering drawing. In these cases, the complicated portions are hardcopied, with final details and dimensions being completed on the drawing board.

There are some interesting problems associated with releasing computer stored data to manufacturing. There is an established need for both conventional drawings for use by inspection and engineering support groups and computer stored data for access by manufacturing. Therefore, the data must be carefully coordinated and controlled. Having parts defined in three-dimensional space and being able to view them from any direction leaves one wondering; what is a "drawing?"

Design Data Sheets - CADD has proven to be very useful when applied to the development and maintenance of design data sheets. Figure 12 shows a hardcopy of a computer stored design data sheet which is used to coordinate fundamental information to the project. This information in the computer is also accessible by all individuals doing design work in any of the software modules.

Figure 13 indicates that many of the internal surfaces are defined and stored as well. The entities labeled RP are surface definitions of longerons, cabin floors, and fuel tanks, and although they show up as lines in these section cuts, are actually three dimensional.

Assembly and Installation Drawings - One of the major advantages in having detailed structural parts defined in the CADD system is the ability to merge them together at the tube, and check fit, in order to eliminate possible interference. When this is accomplished, the results represent an assembly drawing and are beneficial to manufacturing for designing tools and assembly fixtures.

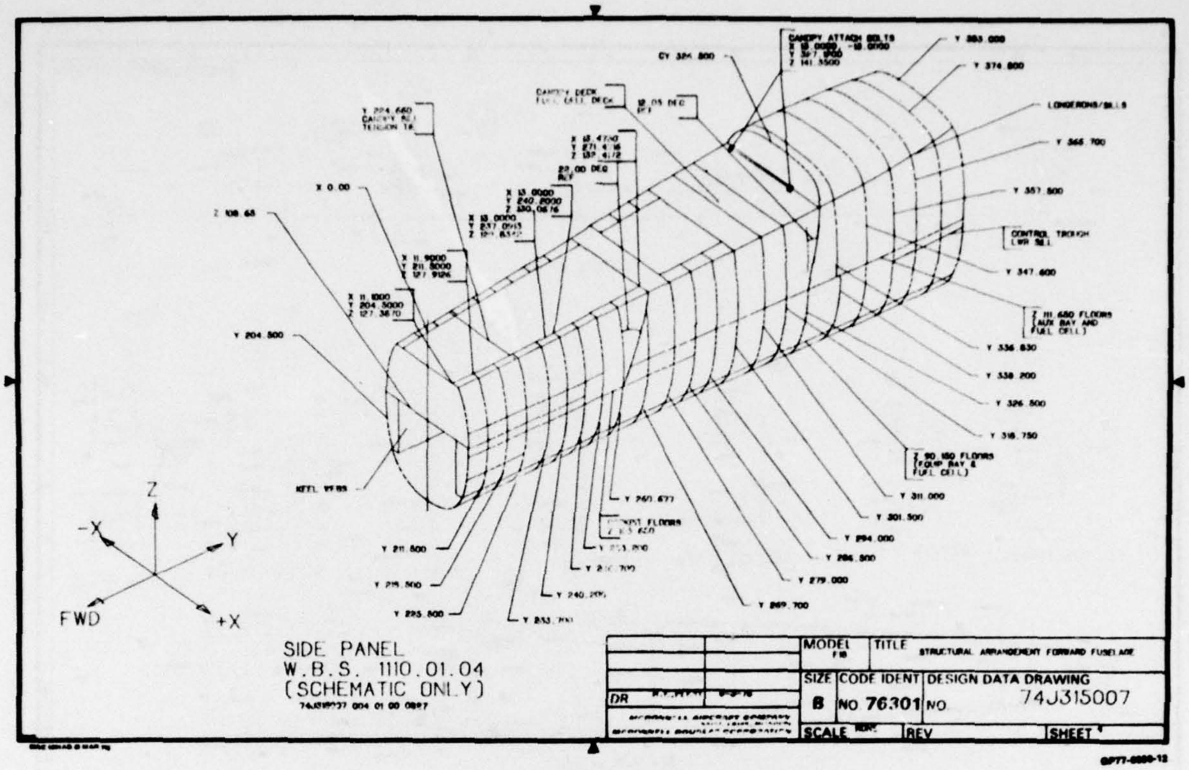



**FIGURE 12**
**DESIGN DATA SHEET**
Schematic Only

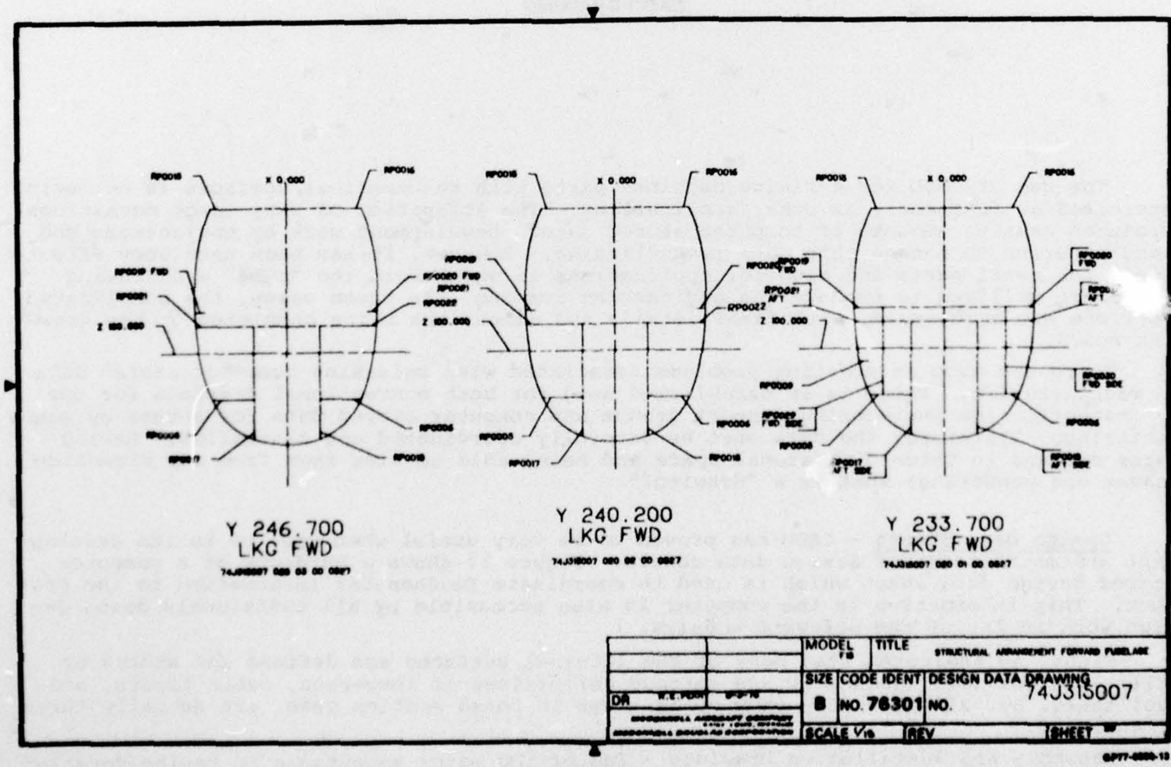



**FIGURE 13**
**STRUCTURAL ARRANGEMENT FORWARD FUSELAGE**

Geometry for Math Models - Many of the engineering technology disciplines require basic airplane geometry data. Figure 14 is a hardcopy of a simplified point/line model created using CADD which will be converted to a finite element model in the CGSA software module, as will be explained later.

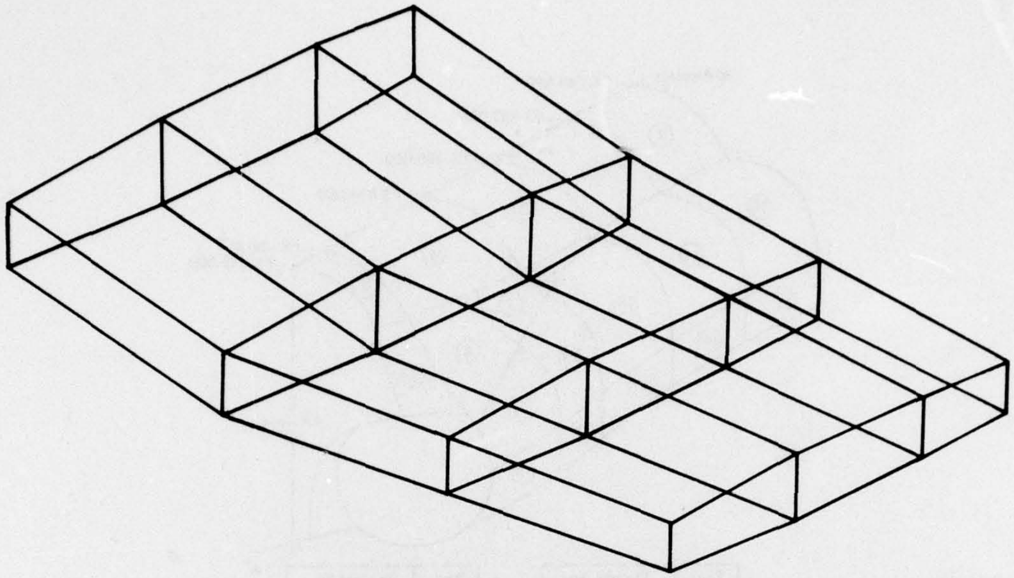



**FIGURE 14**
***POINT LINE MODEL***

This type of data is often generated by projecting the points from some reference plane to the external lofted surface; however, in this example, the desired geometry is not at the exterior surface but at the mid-thickness of the skin. CADD also has routines which allow for this shift in geometry very easily.

Release of Design Drawings to Manufacturing - MCAIR has developed a data management system which allows for formal release of computer stored data from engineering to manufacturing. Strict control is maintained to assure the validity and security of the data.

## LOFT

The Loft engineer provides all mathematical definitions of the external surface of the airplane, and in some cases, such as composite wing skins or internal fuel tanks, internal surfaces.

The loft surfaces, which are stored in the computer, are created with either batch programs or, in recent years, the CALL (computer aided loft lines) software module. The operator of the CALL module has at his disposal many types of mathematical entities and general functions to aid him in creating surface definitions. Figure 15 presents conic and cubic generated surfaces which are produced by a curve moving along directrix control lines.

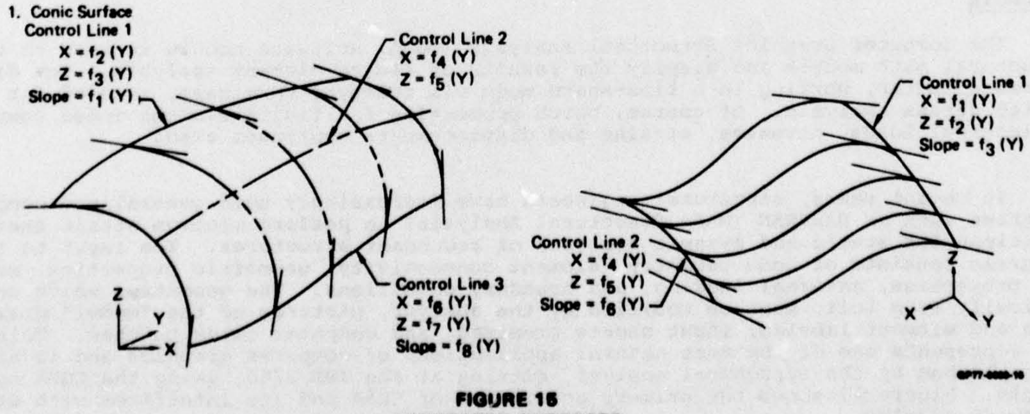
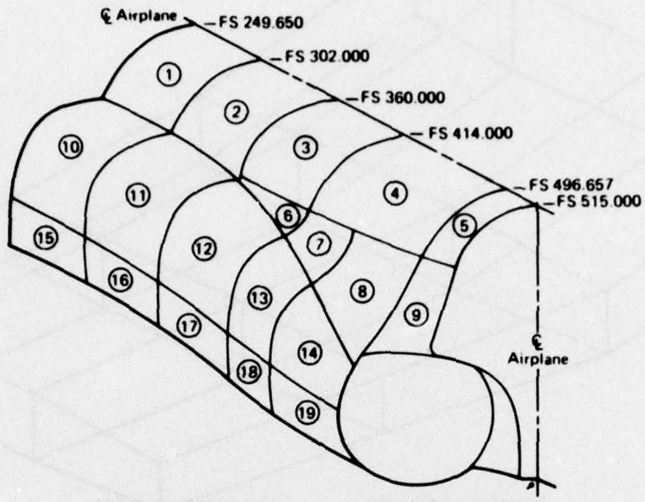



**FIGURE 15**
**GENERATED SURFACES**

The mathematical curves can vary from first-degree (straight line) equations to fourth-degree polynomials. Parametric bicubic patches (surfaces) are also available.

When the loftsman has prepared the surface definitions using the CALL module, he stores them on a permanent file which may be easily accessed by the CADD module. He also publishes a descriptive drawing showing these surfaces along with their identification numbers (Figure 16).




| Zone | Surface No. |
|---|---|
| 1 | RN3201 |
| 2 | RN3205 |
| 3 | RN3206 |
| 4 | RN3242 |
| 5 | RN3243 |
| 6 | RCN011 |
| 7 | RCN016 |
| 8 | RCN012 |
| 9 | RCN014 |

| Zone | Surface No. |
|---|---|
| 10 | RCN001 |
| 11 | RCN002 |
| 12 | RCN004 |
| 13 | RCN005 |
| 14 | RCN006 |
| 15 | RCN060 |
| 16 | RCN058 |
| 17 | RCN057 |
| 18 | RCN069 |
| 19 | RCN054 |

GP77-0030-16

**FIGURE 16**
**SURFACE MAP**

The CADD operator refers to the surface numbers to obtain section cuts, projections to mold line, bend angles for flat patterns, geometry for math models. etc.

Several surface analysis options are available to CALL, providing validation of the work. Included are surface cross diagonals, coordinate curves, lines of constant slope, and center of curvature displays.

To insure efficient utilization of programming resources, communication is maintained between the CALL module, IBM 370 batch, and CDC timesharing programs.

## STRUCTURAL TECHNOLOGY

### STRENGTH

The Computer Graphics Structural Analysis (CGSA) software module is used to create structural math models and display the results of finite element analysis. The direct-access computer, working in a time-share mode via teletype terminals, is used for detailed stress analysis. Of course, batch processing for finite element model computation of internal loads, stresses, strains and displacements continues also.

In recent years, structural engineers have increasingly used generalized computer programs such as NASTRAN (NASA Structural Analysis) to perform minimum strain energy solutions for static and dynamic analyses of redundant structures. The input to these programs consists of node geometry, element connectivity, geometric properties, mechanical properties, external loading, and boundary conditions. The geometry, which comes basically from Loft, must be modified by the analyst, pictures of the "model" drawn, each node and element labeled, input sheets prepared, and computer cards punched. This activity represents one of the most natural applications of computer graphics and is all accomplished by the structural analyst, sitting at the IBM 2250, using the CGSA software module. Figure 17 shows the primary activities of CGSA and its interfaces with other software modules.

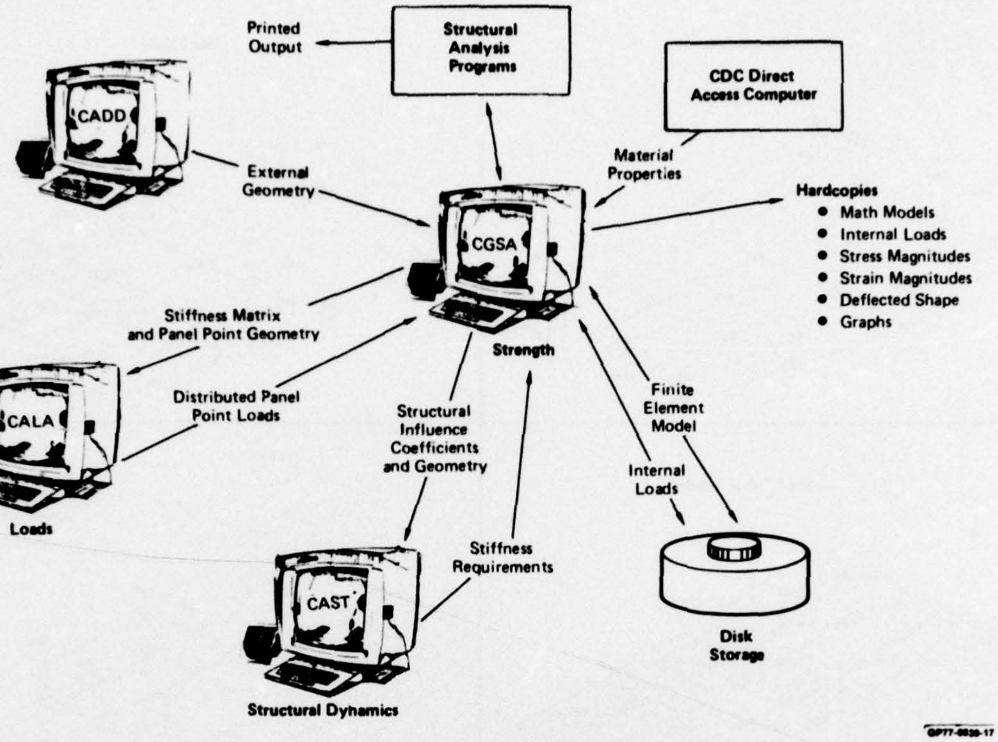



**FIGURE 17**
**CGSA ACTIVITIES**

To define a three-dimensional structural idealization using CGSA, the analyst normally begins with the CADD module, obtains and modifies the lofted geometry, creates the desired points, and stores them in the file, and switches to the CGSA module. He may then define the connectivity, the geometric and mechanical properties of the structural elements, and the external loads and boundary conditions, and update his file.

Many options are available for viewing the graphical representation of the input data at any scale from any angle. Figure 18 depicts computer-generated hardcopies of a few of these options, including element labels, loads, reactions and element properties. The labels of the elements relate to the analysis program printed output. The ability to view, check, and edit the model at the tube and hardcopy it for later reference prevents many input errors.

The structural static or dynamic analysis can be submitted at the graphics terminal by indicating the desired job control language and the structural model title with the light pen. The input card images required by the analysis program are automatically generated on a disk data set from the information stored in the CGSA file. For large finite element models (Figure 19), this may be tens of thousands of card images. The elimination of punched cards has been an important advancement for the structural analyst.

When the analysis program which was submitted from the tube runs in a batch mode, it automatically sends the answers (internal loads, stresses, deflections, etc.) to the CGSA file. Thus, the next time the analyst logs on, he can utilize the options in CGSA which allow the analysis results to be displayed directly on the structural model. Small analyses can be accomplished in real time by solving for the internal loads in an interactive mode.

The output display options of CGSA include internal bar loads, bar stresses, panel shear flow, panel shear stresses, membrane and plate stress, strain, and running load. Also, plots of bar load or stress, shear and bending moment, and deflected shapes are available. Figure 20 presents examples of computer-generated hard copies of some of the display options available.

It is interesting to note that only membrane stresses are calculated and stored by the analysis program; the running loads, strains in any prescribed direction, principal stresses, and principal strains and their associated directions are all calculated by the CGSA module. These options are generated quickly at the graphics console with simple light pen prompting by the operator. The analyst does not take time at the console to study the complete ramifications of the structural analysis, but rather prompts the computer to "hardcopy" the particular display option and load condition he is viewing before proceeding to the next.

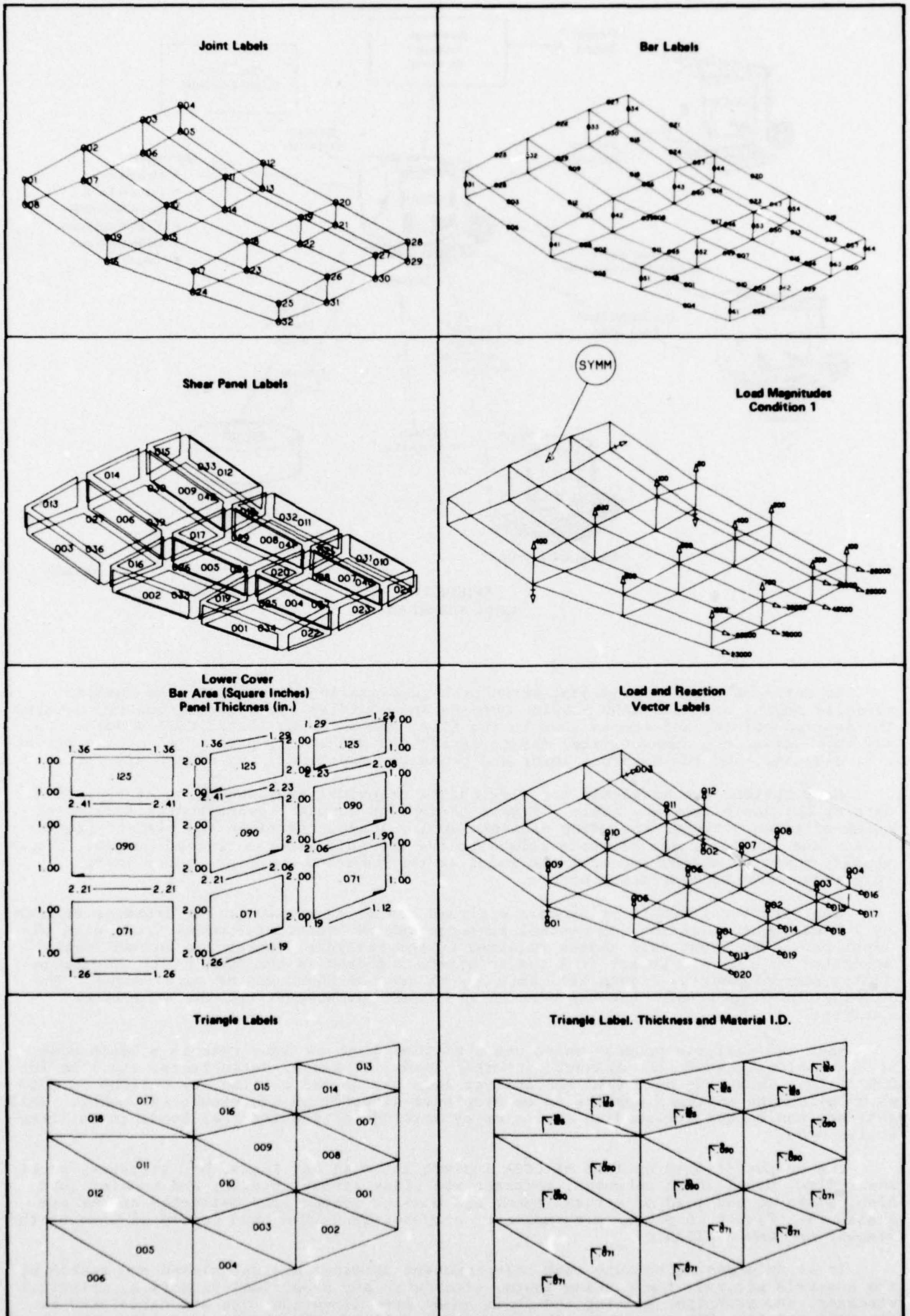



**FIGURE 18**
**STRUCTURAL MATH MODEL**
**Sample Displays of Input Data**

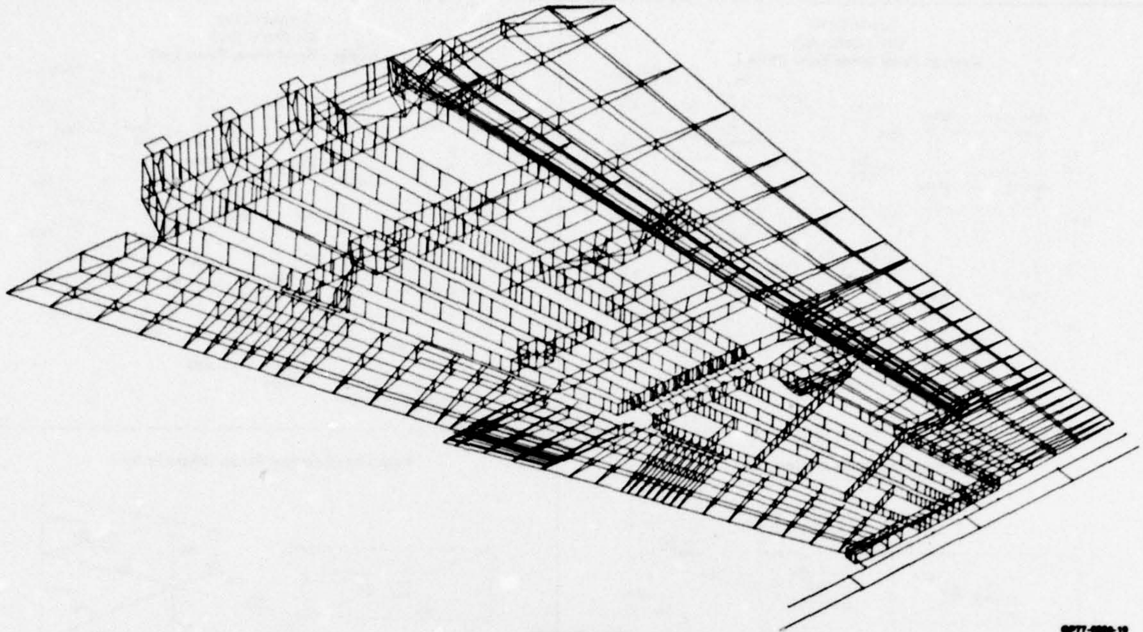


**FIGURE 19**
**STRUCTURAL MATH MODEL**
**Skins Not Displayed**

To ensure a clear, uncluttered hardcopy, the analyst has many options for changing the length of the bars, the size of the panels, the size of the various symbols and text, the view and scale. He also can erase any part of the model or create "free bodies" of desired portions. The hardcopy generated is the entire model selected by the operator, at the scale prescribed, independent of the tube display. This system is supericr to methods which create hardcopies by batch processing in which the user does not know if the numbers are cluttered or the view is poor until his hardcopy arrives.

Figure 20 is based upon a simplified model for clarity. Actual analysis results for project work may contain thousands of elements and many external load conditions. In the past, the structural analyst extracted the internal loads and stresses from large quantities of computer printout.

The CGSA module represents a major advancement in the art of producing internal loads in a timely manner. Unfortunately, this advantage has been somewhat offset by the extreme complexity of new materials such as composites and the increasing severity of design criteria. Thus, CGSA has filled an urgent need to cycle through the design iterations more quickly. To summarize the net results, CGSA has proven to be one of the most effective applications of interactive computer graphics.

STRUCTURAL DYNAMICS

The engineer performing aircraft vibration and flutter analysis is aided by batch programs in addition to the software module Computer Aided Structural Technology (CAST). For expediency in development and testing, the CAST module contains routines serving both weights and structural dynamics needs. Figure 21 describes the functions of the CAST module relative to structural dynamics. The CAST module is compatible with the other software modules allowing for transfer ofdata within the computer as well as file/retrieval and hardcopy. The primary Structural Dynamics capabilities of the CAST modules are:

(a) Creation of subsonic or supersonic unsteady aerodynamic models using CADD geometry.

(b) Creation, review, and editing of input data and submission of analysis programs for vibration, flutter, or matrix algebra. This is accomplished at the graphics terminal and requires no punched cards.

(c) Preprocessor and postprocessor routines for large finite element analysis programs such as NASTRAN for generation of generalized mass matrices, modal deflections and frequencies required for flutter analysis.

(d) Matrix algebra operations in "real" time for small problems.

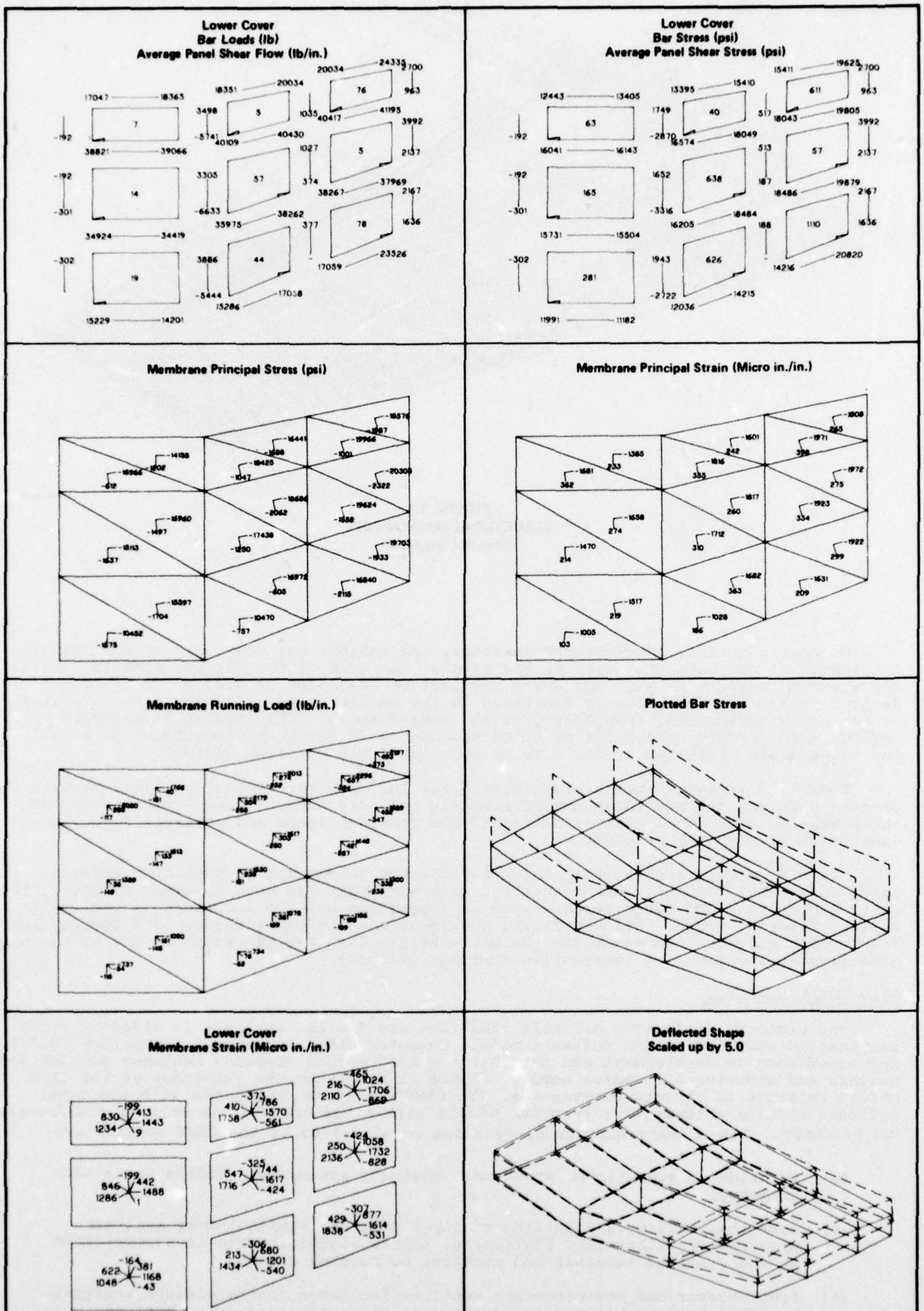



**FIGURE 20**
**STRUCTURAL MATH MODEL**
Sample Display of Analysis Results

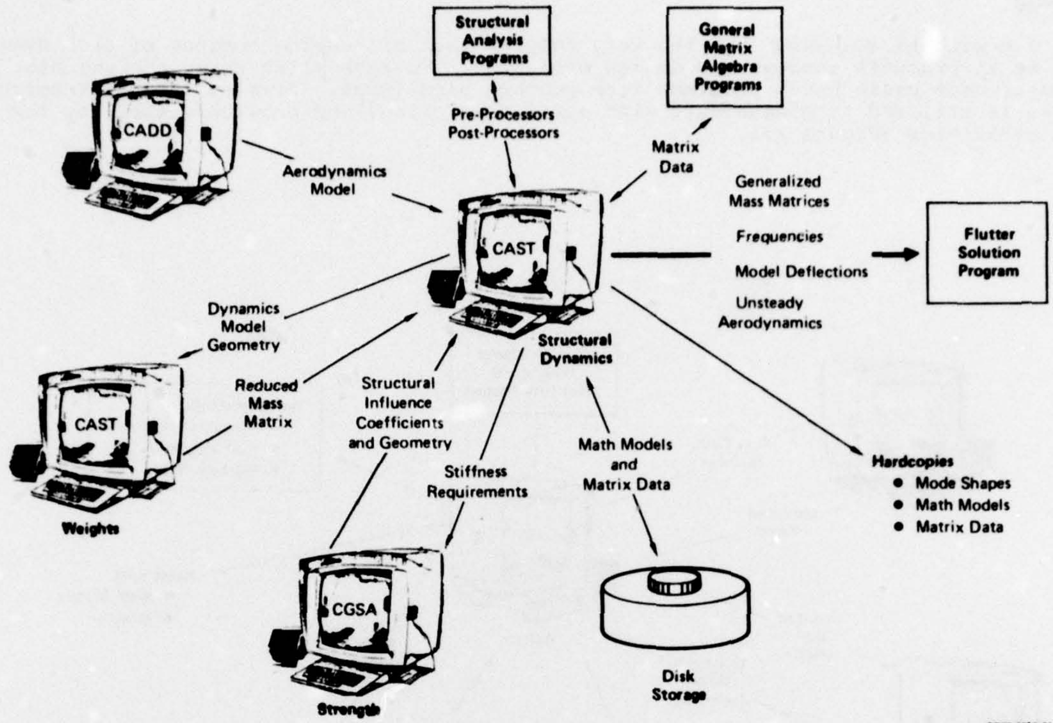



**FIGURE 21**
**CAST ACTIVITIES**
Structural Dynamics

(e) Graphical display of theoretical vibration mode shapes compared with test data stored on a data set (Figure 22).

(f) Data management techniques including the ability to retrieve an influence coefficient matrix from the Strength group or a mass matrix from the Weights group, or to edit binary or card image data sets.

Structural Dynamics engineers still utilize simple beam/rod idealizations; however, the CAST module represents a major step forward in the ability to manipulate data and direct the computer very quickly.

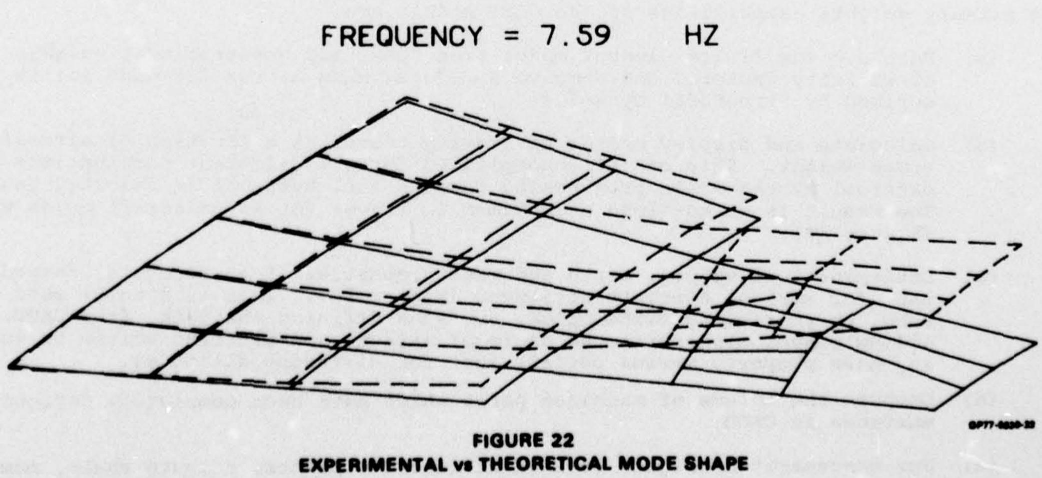



**FIGURE 22**
**EXPERIMENTAL vs THEORETICAL MODE SHAPE**

## WEIGHTS

The weights engineer has the very complex task of keeping account of each detail part as it proceeds through the design evolution. To accomplish this, the weights engineer uses basic batch programs with punched card input. However, the CAST software module is utilized to communicate with other disciplines and provide visibility for certain activities (Figure 23).

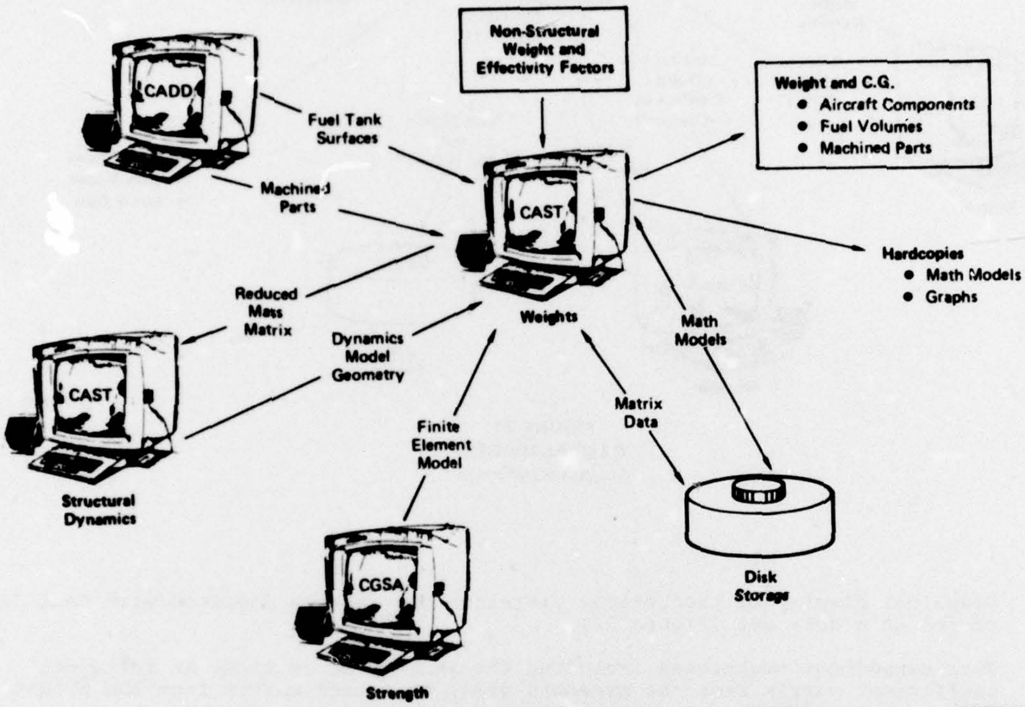



**FIGURE 23**
**CAST ACTIVITIES**
**Weights**

The primary weights capabilities of the CAST module are:

(a) Retrieve the finite element model from CGSA, add nonstructural weights and effectivity factors, and compute a reduced mass matrix for node points prescribed by Structural Dynamics.

(b) Calculate and display center of gravity travel as a function of aircraft gross weight. This can be accomplished for all different combinations of external stores while progressing through fuel burn-off in selected increments. The result is an envelope of maximum CG travel for any aircraft gross weight (Figure 24).

(c) Determine fuel volume, depth and mass properties of an irregular shaped fuel tank for various aircraft attitudes (Figure 25). This is accomplished at the tube, by retrieving mathematical surfaces defining the tank, from CADD, then adding planes describing the angle of attack, and plotting volume or depth or any mass property versus percent fuel for different attitudes.

(d) Compute the volume of machined parts which have been completely defined with surfaces in CADD.

(e) For concentrated weights defined at discrete points, compute shear, moment, and torque curves about some reference axis and plot them (Figure 26). This same capability will work for panel point loads applied to finite element models.

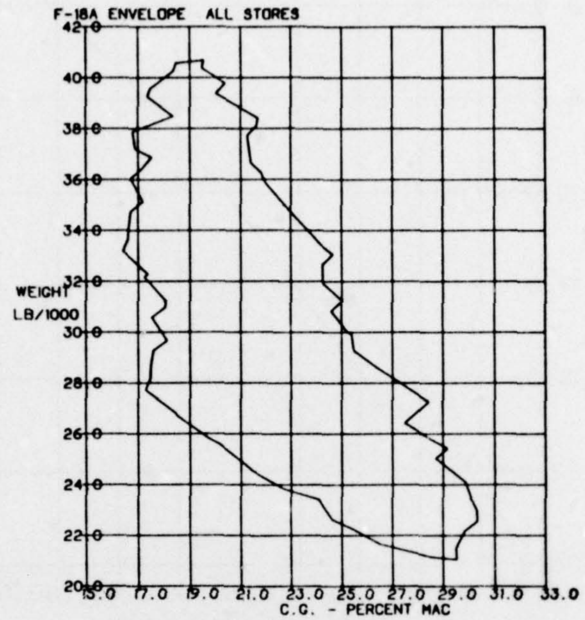
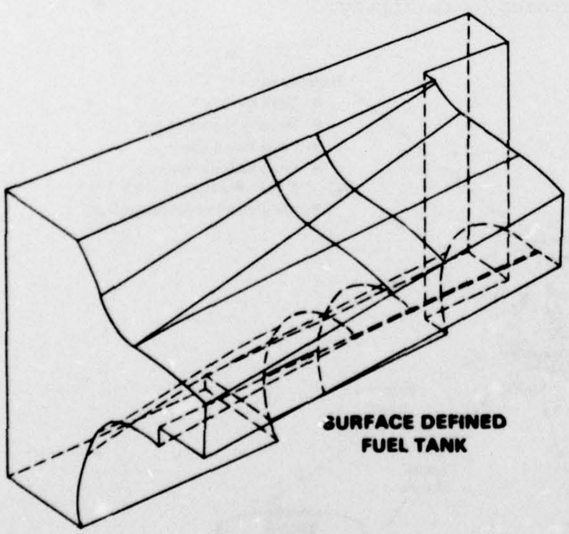



**FIGURE 24**
**F-18A ENVELOPE - ALL STORES**



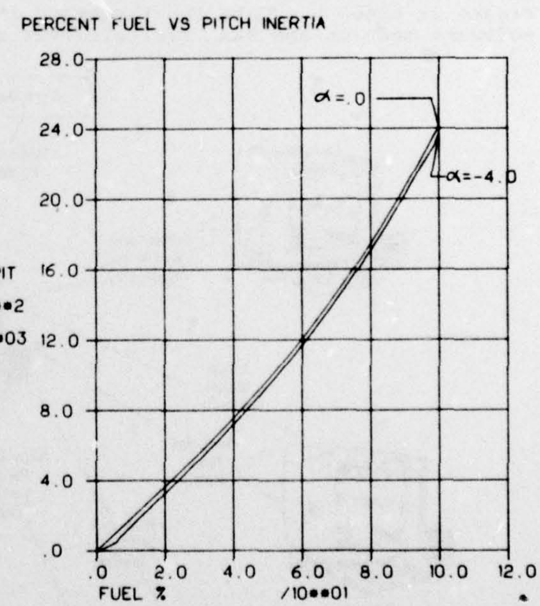




**FIGURE 25**
**HARDCOPIES FROM WEIGHTS MODULE**

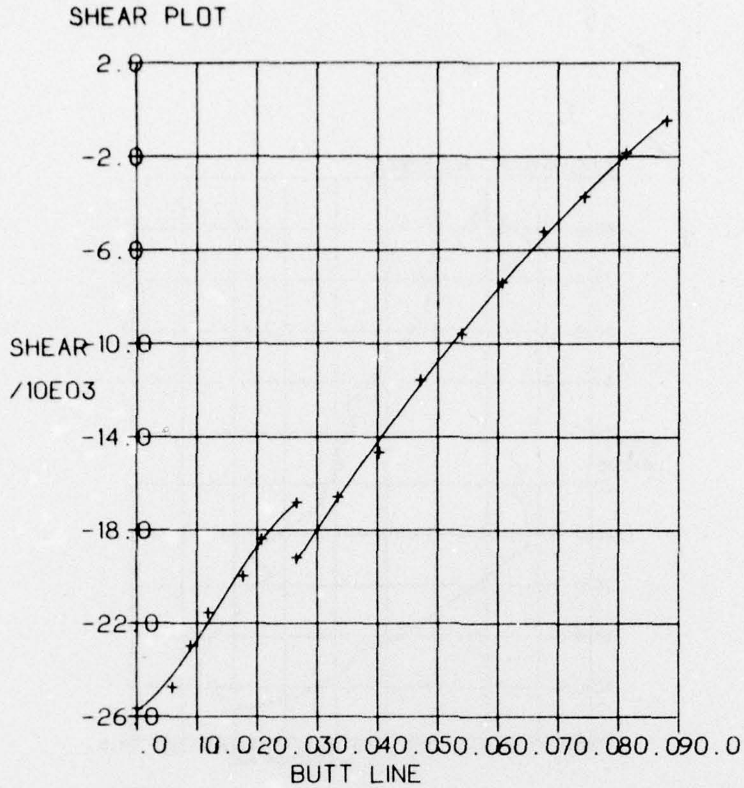



**FIGURE 26**
**SHEAR DIAGRAM**

EXTERNAL LOADS

The loads engineer provides the airplane external design loads. One of the major aids available to him is the Computer Aided Loads Analysis (CALA) software module. Figure 27 shows the CALA functions and interfaces. CALA is compatible with the other software modules and has file/retrieval and hardcopy capability.

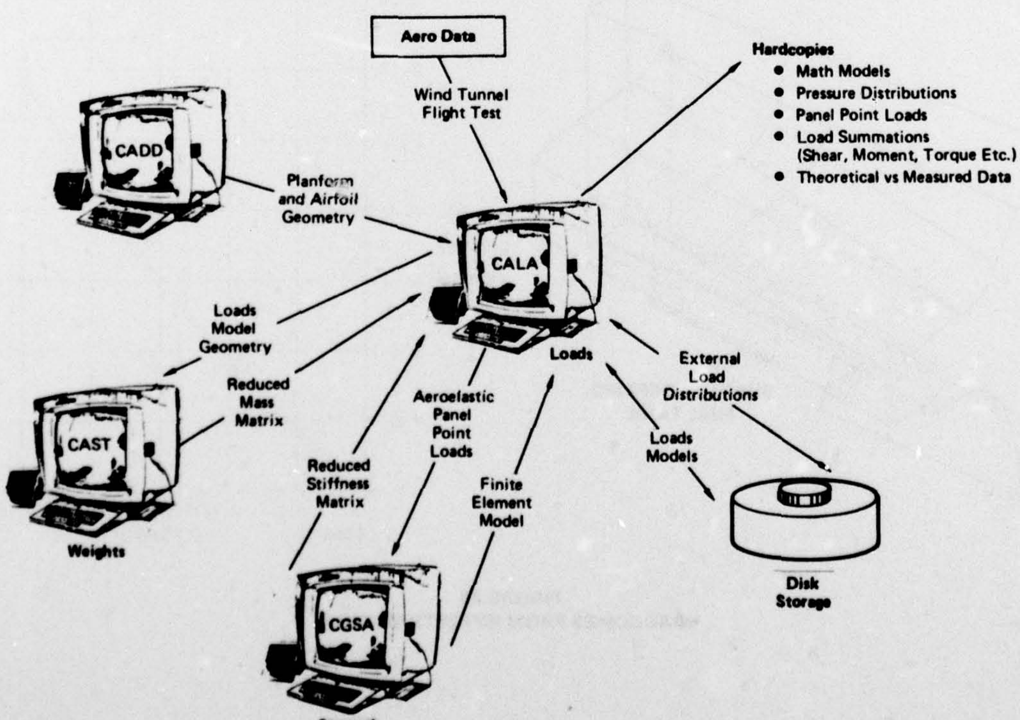



**FIGURE 27**
**CALA ACTIVITIES**

The primary applications of the CALA module are as follows:

(a) Retrieve plan form and airfoil geometry from CADD and reformat it to be compatible with Loads programs.

(b) Retrieve finite element models from CGSA, pick the points which are to be loaded, and reformat the geometry to be compatible with Loads programs.

(c) Utilize a reduced stiffness matrix created by the finite element analysis to include aeroelastic effects due to structural deflections.

(d) Compute aerodynamic pressure distributions due to flight conditions for either rigid or flexible structure.

(e) Make modifications to the theoretical pressure distribution to provide pressure distributions which are compatible with the overall loads on the vehicle determined from wind tunnel or flight test data (Figure 28). These distributions are displayed and modified at the graphics console with complete view, scale, file/retrieval and hardcopy capability.

(f) Compute panel point loads at the location of the points received from CGSA and file them in the correct format for Strength department use (Figure 29).

(g) Compute and display wing load summations, including shear, moment and torque about selected axes, center of pressures, and hinge moments for control surfaces.

Since the external loads and the structural sizing are dependent on each other, the design process is iterative. The CALA system, in conjunction with CGSA has dramatically shortened the time of these iterations. In addition, the Loads engineer has new visibility, fewer errors and freedom from many mundane tasks.

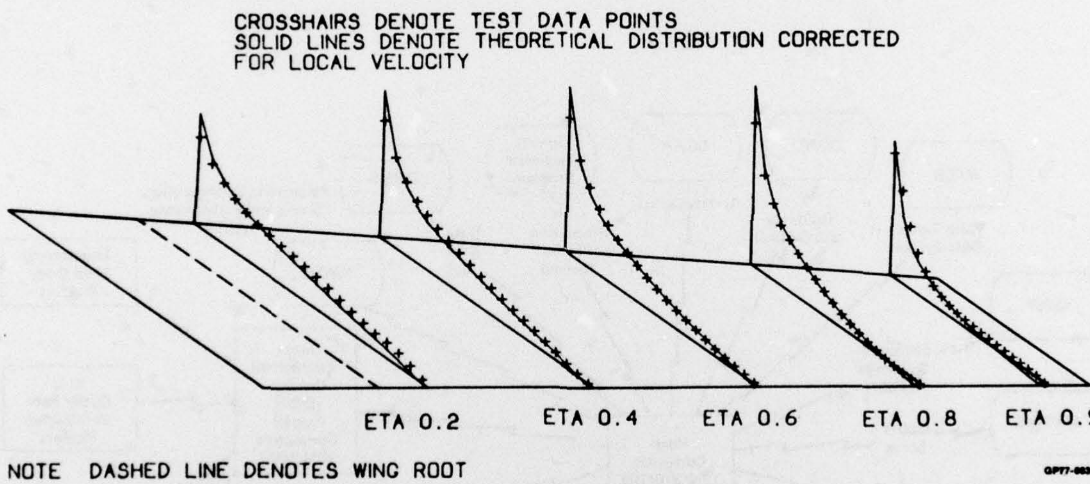



**FIGURE 28**
**NACA RM L51F07 TEST WING**

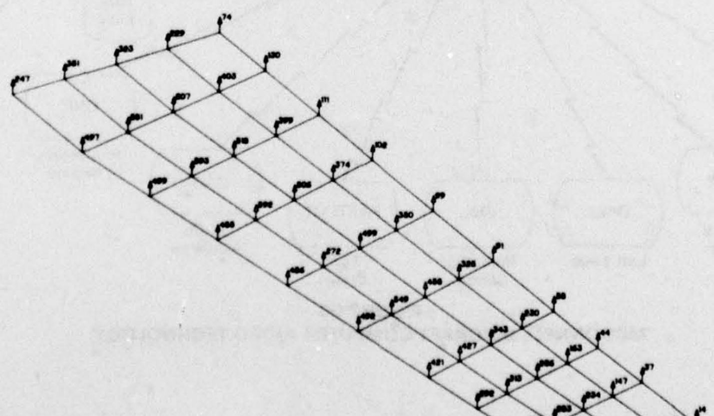


**FIGURE 29**
**FLAPERON APPLIED LOADS**

The CAST and CALA modules are products of an effort to integrate and coordinate the activities of the structural technology disciplines. A basic problem in any engineering organization which utilizes many different computer programs is the duplication of effort resulting from taking data out of the computer and passing it to another discipline only to have them put it back in the computer again. The group of software modules described in this paper have made good progress in combating this problem.

## COMMENTS ON CAD DEVELOPMENT AND IMPLEMENTATION

The development, implementation and maintenance of a complex computer aided design system (Figure 30) requires extremely close coordination. We have found the best solution to be an organization simulating a design project in which all disciplines are represented and co-located. The system should be designed by representatives of the engineers who will ultimately use it. This design should be very specific, including definition of all desired functions and even console displays. Manufacturing personnel developing CAM should also be included with compatible goals and schedules. The software modules for the different disciplines must be planned such that necessary data may be transferred between them. In areas where existing analysis programs, such as NASTRAN, are to be utilized, interfaces must be developed between them and the CAD system.

Another area requiring much attention is the compatibility of the host computer, the CRT terminals, the software, and awareness of future hardware developments.

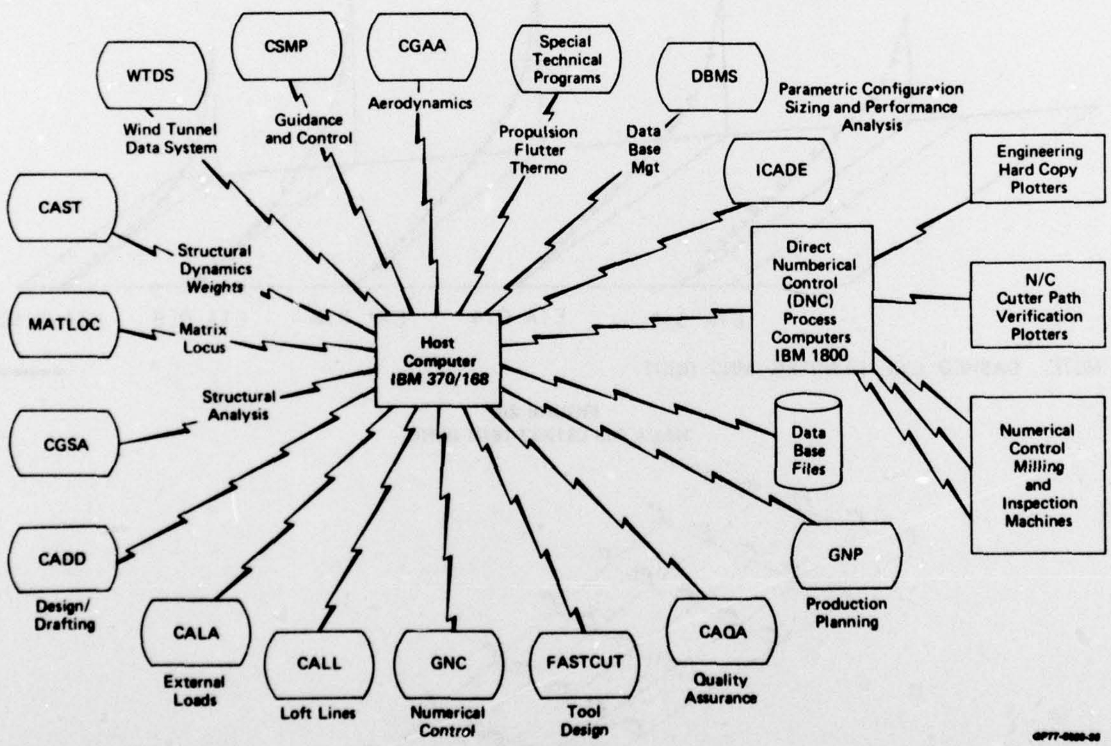



**FIGURE 30**
**MCDONNELL AIRCRAFT COMPUTER AIDED TECHNOLOGY**

The implementation of the system inevitably results in many requests from the operators for additions and improvements; therefore, the project must include a group whose function is to interface with the users for support, definition of new requirements, and training. Currently we have 40 graphics terminals operating 19 hours per day with continued software development and software maintenance provided by our Computer Aided Technology Project. The development of a CAD system such as the one described in this paper, requires strong management support.

## CONCLUSIONS

The whole concept of CAD has enormous potential. It has been proven to be a practical and powerful tool reducing cost, reducing span time for given tasks, reducing engineering errors, while providing better visibility of the entire design process.

# COMPUTER AIDED DESIGN: A MATTER OF CONCERN FOR MANUFACTURING

A report from an AECMA Working Group
presented by

Claude ACKER
Société Nationale Industrielle Aérospatiale
37, boulevard de Montmorency
75016 PARIS
FRANCE

## ABSTRACT

Circumstances have played a major role in the way computer aids have been introduced in the business/ industrial world. Computers have enabled man to achieve such impossible feats as landing on the moon, but it must also be recognized that the pace of their development and the focus of their application in the less demanding environment of everyday life owe relatively little to careful long term planning. The computer's own successes and its present ubiquity are beginning to create problems : chaos may not be near, but if to-morrow's systems are to live up to what is expected of them, it is essential that greater attention be now devoted to try and make sure that they can communicate smoothly and efficiently. Design is part of a greater whole and cannot be a goal in itself : whatever is being designed will have to be manufactured, and, ultimately, sold.

This paper is an attempt to clarify the implications of a global view of the design and manufacturing functions for the design and implementation of computer software. Drawing from the experience of past and present cooperative efforts in this field, it makes some recommendations for priority attention to a few specific problems.

## INTRODUCTION

This paper is intended as a pilot paper and, as such, it should ask more questions than it will be able to answer. It consists mainly of the description of a state of affairs and only some sketchy indications as to what is believed to be a path towards improvement. It is the result of the common efforts of the following group of people :

| | | |
|---|---|---|
| - BELGIUM | Mr. H. RABINOWICZ | SABCA |
| - FRANCE | Mr. C. ACKER (Chairman) | SNIAS |
| - " | Mr. R. VILERS | AMD/BA |
| - GERMANY | Dr. U. GRUPE | VFW-FOKKER |
| - " | Mr. J. NAGEL | DORNIER |
| - " | Dr. H. WALTER | MBB |
| - NETHERLANDS | Mr. A. de GROOT | FOKKER-VFW |
| - SPAIN | Mr. J. DIES NAVARRO | CASA |
| - SWEDEN | Mr. J. JOHANSSON | SAAB SCANIA |
| - UNITED KINGDOM | Mr. G.E.G. BISHOP (Secretary) | H.S.A. |
| - " " | Mr. H.P.Y. HITCH | BAC |
| - " " | Mr. J.B. JACKSON | H.S.A. |

They come from widely different horizons in the aerospace business, as well as geographically, and this wide variety in their background and expertise has contributed to giving the group some exceptional insights into what should be our computer-aided world.

As may be observed, this group is made up of representatives of most major airframe manufacturers in Western Europe ; it was set up late in 1975 at the request of the CTI (an acronym for Commission Technique et Industrielle) of the AECMA (another acronym, for Association Européenne des Constructeurs de Matériel Aérospatial), with the basic responsibility of "making recommendations to the CTI concerning the most effective form of future collaboration in the CAD/CAM field", with the cautionary note "that to-day's concepts of the interface between design, production, inspection etc, which have grown out of historical practices, may not be correct in the future".

The group met a number of times in 1976 and most of what follows is drawn from their discussions and often directly from the report which was delivered to the CTI in November 1976.

## 1. AN ATTEMPT AT PERSPECTIVE

Computers have been with us for close to 30 years now and have, during the last 20 years, spread within the industrial world to reach a point to-day where hardly any aspect of the business life of a company can espace their influence. Computers were introduced relatively early in the aerospace industry, but remained first confined to two types of widely different and completely unconnected applications : typically finding numerical solutions to "insoluble" differential equations and taking care of the pay-roll.

Technological progress has been rapid, bringing with it decreasing hardware costs and increasing availability, especially with the development of remote access terminals and the advent of mini, and now micro, computers. The proliferation of hardware has been closely followed by that of software, since all users were sooner or later tempted to acquire the personalized package best adapted to suit their own particular real or perceived needs.

However it may be said in the users' defence that although computer salesmen have been inclined to claim that their newest electronic wonder will be the final solution to all problems, computer manufacturers have as a whole been remarkably successful at avoiding any liability which could possibly result from their product's failure to solve their client's particular problem. Those clients may find themselves confronted with the alternatives of sending back the machine, of adapting their procedures to the machine, or of devising some kind of compromise through a specially adapted software package which will provide a reasonably adequate answer to the original problem.

The first solution is always difficult to adopt, if only because someone will have to explain to his management why the machine, which was so hotly defended, is after all not really indispensable ; the second is usually painful and sometimes impossible, and the third is the one which is most commonly accepted : many computer users have, at one time or another, been deeply convinced that the only problem a computer was ever basically designed to solve was that of having a favorable impact on its manufacturer's balance sheet.

Even though some unkind spirits may then argue that the success of the computers owes almost as much to the genius of their manufacturers' marketing departments as to any careful, long term, coherent planning by their users, based on an analysis of such things as maximum return on investment, this success is now impossible to deny : computers have sent man safely to the moon and back and they are fast invading our daily life. Probably as a result of this situation, the time now seems to have come when the computer-using community has recognized that the solution to a particular problem often results in the creation of a set of data to be used in turn by the neighbouring department or firm in solving its own problem : as the use of computers spreads, interface problems crop up ; islands of automated data processing begin to realize they are often separated by wide gaps, the bridging of which requires all too often painstaking manual efforts and costly delays. The contrast between the efficiency promoted by computer usage and the wasted efforts observed wherever manual links have to be operated between automated systems, has brought about an awareness of the communication problems created by the now ubiquitous computer.

The creation of the AECMA Working Group was an expression of the feeling that computer assistance to design and manufacturing has now reached a critical stage in the European aerospace industry, where it becomes essential to make sure that new software developments are compatible and can interface as smoothly as possible. The cost of those developments is high and suitably skilled personnel are rare : while many of the bigger aerospace companies have started independent - and sometimes very costly - projects concentrating on subjects of particular relevance to their own problems, none has really produced and begun to implement an overall coordinated plan ; the need to avoid the waste of rare talent and money in duplications, and the feeling that similar products probably create similar problems, also suggest that it might be worth while to investigate the advisability and practicality of joint research efforts.

## 2. WHY CAD ?

CAD, Computer Aided Design, is presently a very popular acronym. What does it cover ? What does it do ?

It usually calls to mind a host of other acronyms : CADAM, GEOLAN, CADDS, AUTOKON, CAST, NGG ... and evokes visions of cathode ray tubes, automatic drafting tables, disk packs, telephone lines ... and thousands if not millions of dollars, francs, yen, kroners ... All of these packages are certainly useful and all accomplish a variety of amazing tasks, but may possibly be suspected of being most beneficial to those for whom they are the end product : the software houses, the application program offices of computer manufacturers, perhaps even the in-house software departments of the user companies.

For most companies, design is not an ultimate goal : very few, if any, can sell a pile of drawings, even if they have been computer generated. It has to be clearly recognized that for the overwhelming majority of companies, the end product is an object for sale, be it an aircraft, a washing machine, a computer or a highway. It is desirable to be able to design this object efficiently and cheaply, but it is totally useless, unless you can also <u>make</u> it, and what really counts is your overall efficiency, not just that of your Design Office.

<u>This</u> is the key to the title of this paper : CAD is a matter concern for Manufacturing, because Manufacturing ultimately has to make what has been designed.

An isolated CAD runs the risk of being at best a stop-gap solution for localized gains, and is unlikely to yield optimal results on a global level ; with a little lack of luck, it may even prove to have negative results. Speaking of CAD alone tends to encourage a trend towards a dangerous isolation, and while it may be too extreme to claim that Design is only the first step in the Manufacturing Process, and thus proscribe CAD in favor of CAM, it is probably wise to associate both in CAD/CAM, as they are inevitably linked in the real world.

## 3. FOCAL POINTS

In order to conduct an orderly investigation of the field of CAD/CAM, an effort must be made to avoid being trapped in the maze of labels which different companies will use to identify the same basic functions which somehow have to be performed, between the moment when the object or product is first defined and the moment when it comes out of the factory door.

The Working Group made such an effort, and relatively easily reached a consensus that although most of the activities are partially computerized and offer substantial possibilities for further development, three functions deserve to be given priority attention in a review of possible joint initiatives. Their outputs play a major role in communications within each company, and are likely to do so in any co-operative program between companies. These functions are :

- the representation of geometry,
- process planning,
- the creation and manipulation of parts list data.

Not unexpectedly they all cut across the border between Design and Manufacturing and any development will require collaboration between specialists in different fields and careful consideration of the needs of very diverse users.

3.1. The representation of geometry.

There is probably no doubt that the representation of geometry or shape is an absolutely basic function : an enormous amount of information about shapes is handled every day within and between companies, within Design as well as Manufacturing. If one cannot quite say that shape is the object, it is certainly a major part of it, especially if such notions as surface finish and tolerances are included.

Shape has traditionally been represented by drawings : the output of the drawing office of an airframe manufacturer is typically some 50 000 drawings per aircraft, about 60 % of which is geometric or shape data.

Shape can of course be represented in other ways :

- words, but it is well known that "a picture is worth a thousand words",
- or numbers, which is the way computers like it.

The drawing problem can itself be subdivided and different aspects having peculiar requirements can be singled out, such as :

- 3 D doubly curved surfaces,
- 3 D geometry of points, straight lines and planes,
- 2 D geometry for piece parts definition,
- 3 D geometry of piece parts,
- kinematics,
- geometry of wind tunnel models,
- systems schematics,
- illustration for manuals ;

and computing power has been applied to them through a large number of specialized and independent projects which have met varying degrees of success.

3.2. Process planning :

Process planning is the activity concerned with answering the question "how do you manufacture your product ?", separate from "what is your product ?" and also from "where and when do you manufacture it ?". Its goal is to define a sequence of steps which will result in the transformation of something considered as the raw material or blank into something more elaborate or complete called product.

A great many different levels of detail can be considered, and the difficulty and nature of the effort involved in the activity will depend considerably on the chosen level of description : the question "how do you build this aeroplane ?" can be answered in many different ways, but "you buy a company which knows how to do it", while possibly satisfactory for a financier, can hardly be called a process plan. The output of process planning, as most commonly understood, is a document describing the manufacturing of a part or the building of an assembly through a list of orderly steps, the size of which will depend mainly upon factors such as the skills of the labour force or the existence of detailed company standards.

In order to be able to perform their task, planners need basically two sets of information :

- a description of the product or goal to be achieved : this will generally consist of a set of engineering drawings ;
- a description of the existing manufacturing facilities.

They also have access to planning manuals, manufacturing instructions and other similar documents under a variety of labels ; but these are nothing more than dictionaries, and as such they are not much help, unless one has a firm grasp of grammar and basic spelling. This is why process planners are usually experienced men who have been promoted from the shop floor : they are thus able to draw on practical knowledge and experience to produce process plans which are the results of a long learning by trial an error.

There are many reasons to try to automate this process and among the most pressing are the following :

- experienced men are rare and difficult to replace : their time should not be unnecessarily wasted in clerical occupation ;

- diffusion of experience is a slow process and often meets with a large degree of resistance, if not outright hostility, in large, multi-plant companies ;

- standardization of the best process plans and its related advantages tend to become a remote, almost impossible goal.

This is presently widely realized and this area is currently among the most active in CAD/CAM development.

3.3. The creation and manipulation of parts lists data.

Computer held files of aircraft parts lists are rapidly becoming the centre of technical and managerial control of aircraft projects.

Many companies have invested substantial sums in such file systems :

- because control of the creation of the data provides a key control on the progress of the design/production activity ;

- because the files provide thereafter the essential data and control between :

  . design and production,

  . manufacturer and sub-contractor,

  . product support and customer ;

- because the use of such computer systems is becoming essential to contain the large clerical effort that is involved in recording and generally using the very large volumes of data in a modern aircraft.

Possibly the most significant current development in this area is the move to provide engineers with terminals allowing them direct access to the files. This facility is proving of major assistance :

- it is making the introduction of data in the system and its administration easier and easier ;

- it is helping to gain significant assistance from engineers and production staff, as they accept the computer files as "their own" ;

- files are at least as up to date as the equivalent traditional records ;

- the computer terminals provide very efficient transmission of information throughout an organization.

These developments are particularly significant to aircraft projects involving organizations in different locations. The new on-line computer systems operate readily through standard telephone links, and the interaction which this allows between two or more organizations, during the critical period of design and prototype production, could be immensely valuable. Much of the duplication of effort and the associated delays which occur as each organization rewrites and checks information could be avoided.

However, the progress towards the new computer systems is now raising significant problems. Engineers will soon expect an interactive computer system to handle this type of information, and whilst this is now becoming available within a single unit, it will present major problems in a multi-company environment. Under traditional clerical methods, data was issued in batches, and was translated manually into each organization's own format on a reasonably leisurely timescale. This was consistent with batch computer methods, and few problems have been met in multicompany projects using such batch computer systems.

But on-line working is removing this buffering between computer systems, and organizations working on the same project could have to arrange interfaces between a number of highly interactive computer systems built around different computers, different methods and different data formats.

## CONCLUSION : A PROPOSAL FOR ACTION

**It should be quite obvious that the value of any work done in the areas we have just surveyed will depend to a large extent on its integration within a broader scheme : geometry representation is needed by the design office, but also, among others, by the tooling department, and by people preparing spare parts catalogs, user training manuals etc ; it will be a major part of the input into process planning, who may in turn use it to produce work instruction sheets, and as far as parts lists manipulations are concerned, they will be performed by practically every department in the company.**

**As these activities cut across departmental lines within a company, they will cut accross company lines in the case of cooperative projects. It would thus seem essential that efforts towards producing computer systems capable of helping to perform these tasks be as broad-based as possible, both in terms of expertise of the developing teams, and in terms of the participation of different companies.**

It became rapidly quite clear to the Working Group that different solutions had to be adopted, depending on the scope of the task at hand. Part-time, voluntary committee work was felt to be most adequate for information gathering through general surveys, technical policy formulation and eventually guidance and control of detailed work performed by others. This solution, however, becomes rapidly impractical as either the specialization or the magnitude of the assignment increases, and the organization of full-time or semi full-time task forces soon becomes mandatory.

The Working Group made several recommendations for action, the implementation of which will require that kind of set-up ; four of them deal with the representation of geometry :

- definition of interfaces between existing 3D doubly curved surface definition systems, and between those and NC programming systems,
- in-depth survey of existing 3D doubly curved surface definition systems,
- state-of-the-art review, cost effectiveness study and proposed broad specification for a 3D piece parts geometry definition system,
- detailed specifications for a wiring diagram production and updating system,

and one with problems associated with parts lists handling.

To go one step further and launch full scale development projects requires, in the opinion of the Working Group, a quantum jump in organization. A fund raising mechanism and a controlling structure (be it a very light one) have to be built up. This is a major undertaking, the cost and difficulty of which should not be minimized.

Experiments into such cooperative research have already been made, notably in France, in Germany, in the Scandinavian countries. In the United States, two major projects are now in progress, which are intended to benefit a large segment of the industry : IPAD (Integrated Program for Aerospace Vehicle Design) sponsored by NASA and ICAM (Integrated Computer Aided Manufacturing) sponsored by the US Air Force. On the international level, CAM-I, Inc. (Computer Aided Manufacturing-International), a not-for-profit research organization, with headquarters in Arlington, Texas, and about 70 members, 15 of which are European and 9 Japanese, is doing very valuable work, notably in the field of Process Planning : the Working Group has indeed recommended that membership in that organization be encouraged among the European aerospace industry, whatever decision is ultimately made as to the possibility and advisability of launching specific full-scale AECMA projects.

## REPORT DOCUMENTATION PAGE

| 1. Recipient's Reference | 2. Originator's Reference | 3. Further Reference | 4. Security Classification of Document |
|---|---|---|---|
| | AGARD-R-662 | ISBN 92-835-1267-7 | UNCLASSIFIED |

| | |
|---|---|
| 5. Originator | Advisory Group for Aerospace Research and Development<br>North Atlantic Treaty Organization<br>7 rue Ancelle, 92200 Neuilly sur Seine, France |
| 6. Title | COMPUTER AIDED DESIGN |
| 7. Presented at | the 45th Structures and Materials Panel Meeting, Voss, Norway, September 1977. |

| 8. Author(s) | 9. Date |
|---|---|
| Various | December 1977 |

| 10. Author's Address | 11. Pages |
|---|---|
| Various | 32 |

| | |
|---|---|
| 12. Distribution Statement | This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications. |

13. Keywords/Descriptors

| | | |
|---|---|---|
| Computer aided design | Computer programs | Aerospace industry |
| Design | Modules | |
| Computer systems hardware | Cost effectiveness | |

14. Abstract


While some of the largest aerospace companies within the NATO community have already installed very complex, but nevertheless modulized software and hardware configurations for computer-aiding the design process in its different fields, other companies apply only specialized and/or isolated modules of software and hardware configurations.

This situation is caused not only by the engineering capacity and amount of money involved, but stems also from the lack of criteria by which the benefits of money invested may be estimated. The latter holds true especially because design directly causes only a small proportion of costs, whereas up to 80 percent of total product costs may be influenced by the design process. Thus much of the benefit of introducing more effective means and methods into the design process have to come downstream from material supply and manufacturing of a product.

From this it follows that each isolated module of software and hardware must not only fit into a general concept for the design process of one company, but must have a well defined interface with manufacturing facilities of the same company. This point becomes its special feature if cooperative programs between two or more aircraft companies in different countries are concerned.

The pilot papers contained in this publication will help to define the present possibilities, needs and applications of CAD in the design process, bearing in mind that design is not an aim in itself, but only one step towards manufacturing and selling a product.

AGARD Report No. 662
Advisory Group for Aerospace Research and Development, NATO
COMPUTER AIDED DESIGN
Published December 1977
32 pages

While some of the largest aerospace companies within the NATO community have already installed very complex, but nevertheless modulized software and hardware configurations for computer-aiding the design process in its different fields, other companies apply only specialized and/or isolated modules of software and hardware configurations.

This situation is caused not only by the engineering capacity and amount of money involved, but stems also

P.T.O.

AGARD-R-662

Computer aided design
Design
Computer systems
hardware
Computer programs
Modules
Cost effectiveness
Aerospace industry

AGARD Report No. 662
Advisory Group for Aerospace Research and Development, NATO
COMPUTER AIDED DESIGN
Published December 1977
32 pages

While some of the largest aerospace companies within the NATO community have already installed very complex, but nevertheless modulized software and hardware configurations for computer-aiding the design process in its different fields, other companies apply only specialized and/or isolated modules of software and hardware configurations.

This situation is caused not only by the engineering capacity and amount of money involved, but stems also

P.T.O.

AGARD-R-662

Computer aided design
Design
Computer systems
hardware
Computer programs
Modules
Cost effectiveness
Aerospace industry

AGARD Report No. 662
Advisory Group for Aerospace Research and Development, NATO
COMPUTER AIDED DESIGN
Published December 1977
32 pages

While some of the largest aerospace companies within the NATO community have already installed very complex, but nevertheless modulized software and hardware configurations for computer-aiding the design process in its different fields, other companies apply only specialized and/or isolated modules of software and hardware configurations.

This situation is caused not only by the engineering capacity and amount of money involved, but stems also

P.T.O.

AGARD-R-662

Computer aided design
Design
Computer systems
hardware
Computer programs
Modules
Cost effectiveness
Aerospace industry

AGARD Report No. 662
Advisory Group for Aerospace Research and Development, NATO
COMPUTER AIDED DESIGN
Published December 1977
32 pages

While some of the largest aerospace companies within the NATO community have already installed very complex, but nevertheless modulized software and hardware configurations for computer-aiding the design process in its different fields, other companies apply only specialized and/or isolated modules of software and hardware configurations.

This situation is caused not only by the engineering capacity and amount of money involved, but stems also

P.T.O.

AGARD-R-662

Computer aided design
Design
Computer systems
hardware
Computer programs
Modules
Cost effectiveness
Aerospace industry

from the lack of criteria by which the benefits of money invested may be estimated. The latter holds true especially because design directly causes only a small proportion of costs, whereas up to 80 percent of total product costs may be influenced by the design process. Thus much of the benefit of introducing more effective means and methods into the design process have to come downstream from material supply and manufacturing of a product.

From this it follows that each isolated module of software and hardware must not only fit into a general concept for the design process of one company, but must have a well defined interface with manufacturing facilities of the same company. This point becomes its special feature if cooperative programs between two or more aircraft companies in different countries are concerned.

The pilot papers contained in this publication will help to define the present possibilities, needs and applications of CAD in the design process, bearing in mind that design is not an aim in itself, but only one step towards manufacturing and selling a product.

Two papers presented at the 45th Structures and Materials Panel Meeting, Voss, Norway, September 1977.

ISBN 92-835-1267-7

from the lack of criteria by which the benefits of money invested may be estimated. The latter holds true especially because design directly causes only a small proportion of costs, whereas up to 80 percent of total product costs may be influenced by the design process. Thus much of the benefit of introducing more effective means and methods into the design process have to come downstream from material supply and manufacturing of a product.

From this it follows that each isolated module of software and hardware must not only fit into a general concept for the design process of one company, but must have a well defined interface with manufacturing facilities of the same company. This point becomes its special feature if cooperative programs between two or more aircraft companies in different countries are concerned.

The pilot papers contained in this publication will help to define the present possibilities, needs and applications of CAD in the design process, bearing in mind that design is not an aim in itself, but only one step towards manufacturing and selling a product.

Two papers presented at the 45th Structures and Materials Panel Meeting, Voss, Norway, September 1977.

ISBN 92-835-1267-7

from the lack of criteria by which the benefits of money invested may be estimated. The latter holds true especially because design directly causes only a small proportion of costs, whereas up to 80 percent of total product costs may be influenced by the design process. Thus much of the benefit of introducing more effective means and methods into the design process have to come downstream from material supply and manufacturing of a product.

From this it follows that each isolated module of software and hardware must not only fit into a general concept for the design process of one company, but must have a well defined interface with manufacturing facilities of the same company. This point becomes its special feature if cooperative programs between two or more aircraft companies in different countries are concerned.

The pilot papers contained in this publication will help to define the present possibilities, needs and applications of CAD in the design process, bearing in mind that design is not an aim in itself, but only one step towards manufacturing and selling a product.

Two papers presented at the 45th Structures and Materials Panel Meeting, Voss, Norway, September 1977.

ISBN 92-835-1267-7

from the lack of criteria by which the benefits of money invested may be estimated. The latter holds true especially because design directly causes only a small proportion of costs, whereas up to 80 percent of total product costs may be influenced by the design process. Thus much of the benefit of introducing more effective means and methods into the design process have to come downstream from material supply and manufacturing of a product.

From this it follows that each isolated module of software and hardware must not only fit into a general concept for the design process of one company, but must have a well defined interface with manufacturing facilities of the same company. This point becomes its special feature if cooperative programs between two or more aircraft companies in different countries are concerned.

The pilot papers contained in this publication will help to define the present possibilities, needs and applications of CAD in the design process, bearing in mind that design is not an aim in itself, but only one step towards manufacturing and selling a product.

Two papers presented at the 45th Structures and Materials Panel Meeting, Voss, Norway, September 1977.

ISBN 92-835-1267-7